MAT-92-03

Review of Integrated Weed Management for Ontario Roadsides

Ontario

Ministry of Transportation

Research and Development Branch

Ontario
Ministry of Transportation
Research and Development Branch

Documentation Page

MAT-92-03

Review of Integrated Weed Management for Ontario Roadsides

Author(s): S. Monet - Ecological Services for Planning Ltd.

Date Published: March, 1992

Published by: Research and Development Branch, MTO

Contact Person: Nancy Cain, Materials Office
(416) 235- 4693

Abstract: This review investigates integrated weed management (IWM) techniques that could apply to roadside vegetation management in Ontario conditions. IWM incorporates multiple approaches including cultural practices; biological weed control; competitive vegetation; allelopathic species; and mechanical, physical and chemical control.

Competitive vegetation could be incorporated by encouraging development of naturally occurring communities of herbaceous or shrub vegetation that are resistant to invasion by weeds or brush due to allelopathy or competition. In more intensively managed areas, planting of competitive ground covers is an alternative. Roadside turf mixtures should be evaluated with competitive ability as a prime consideration. Establishment of vegetation on construction sites should promote rapid, vigorous growth of desirable plants to minimize invasion of weeds on exposed soil. In existing turf areas, maintenance should encourage vigorous growth to compete with undesirable vegetation.

Targeted mowing of noxious weeds may augment chemical and cultural control efforts. In the long term, biological control agents could be used to supplement other methods. There is a need for continued development of chemical control options to optimize effectiveness by improved timing and to expand the use of targeted applications. Chemical control can be combined with technologies such as cut surface applications for brush control, and programs of herbicide use, mowing, fertilization and overseeding for noxious weed control.

The development of IWM programs is discussed and sample IWM programs are outlined for 1) brush control and 2) noxious weed control in turf areas. The report concludes by summarizing existing technologies, and ones requiring further development under Ontario conditions.

Comments: Research in 1992 is evaluating maintenance practices to increase ROW turf competitiveness, comparing the effectiveness and the economics of methods for different brush control, and evaluating methods of establishing perennial, low-maintenance wildflower mixtures.

Key Words: Roadside vegetation management, weed control, brush control, integrated weed management, biological control, competitive vegetation, noxious weeds.

Copyright Status: Crown copyright © 1992 Ministry of Transportation

92-04313/

MAT-92-03

Review of Integrated Weed Management for Ontario Roadsides

S. Monet
Ecological Services for Planning Ltd.

Published by
The Research and Development Branch
Ontario Ministry of Transportation

Published without prejudice as to the application of the findings.
Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the Ministry.

For additional copies, contact:
The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 235-3480
Fax: (416) 235-4872

March 1992

Table of Contents

1/ **Introduction** 1

1.1/ Background 1

1.2/ Study Objectives 3

2/ **Study Approach** 4

3/ **Integrated Weed Management (IWM)** 4

4/ **Literature Review** 6

4.1/ Introduction 6

4.2/ Competitive Vegetation 6

4.2.1/ Control of Undesirable Vegetation and Maintenance of Vegetative Cover 6

4.2.1.1/Plant Competition 6

4.2.1.2/Allelopathy 16

4.2.1.3/Grasses 17

4.2.1.4/Establishment of Herbaceous Vegetation 18

4.2.2/ Competitive Control of Milkweed and Thistles 19

4.3/ Mechanical Control 19

4.3.1/ Brush Control and Mowing 19

4.3.2/ Mechanical Weed Control Along Structures 20

4.3.3/ Mechanical Weed Control in Ditches 20

4.3.4/ Mechanical Control of Noxious Weeds 21

4.4/ Biological Control 21

4.5/ Chemical Control 23

4.5.1/ Application Technology 24

4.5.2/ Chemical Control of Brush 25

4.5.2.1/Basal Techniques 25

4.5.2.2/Broadcast Applications 25

4.5.3/ Chemical Control of Weeds in Ditches 27

4.5.4/ Chemical Control in Landscape Plantings 27

4.5.5/ Chemical Control of Noxious Weeds 27

4.6/ Combined Control Methods 29

4.6.1/ Brush Control 29

4.6.2/ Control of Noxious Weeds 29

4.7/ Reducing Weed Problems Following Construction 30

4.7.1/ Early Establishment of Competitive Vegetation 30

Table of Contents (continued)

4.7.2/ Construction Treatments to Minimize Early Breakdown of Structures 33

4.7.3/ Survival of Amenity Plantings 33

5/ Development of Weed Control Programs Using the IWM Approach 34

5.1/ Integrated Program for Brush Control 35

5.2/ Integrated Program for Turf Weed Control 36

5.3/ Research Required for Integrated Programs 37

6/ Proposed Areas of Research 38

6.1/ Introduction 38

6.2/ Research Project 1 - Establishment of Low-Growing Vegetation Communities 38

6.2.1/ Objectives 38

6.2.2/ Scope 39

6.2.3/ IWM Context 39

6.3/ Research Project 2 - Establishment of Competitive Grasses and Forbs 40

6.3.1/ Objectives 40

6.3.2/ Scope 40

6.3.3/ IWM Context 40

6.4/ Research Project 3 - Comparative Study of Low-Volume Chemical and Non-Chemical Selective Vegetation Control Along Ontario Roadsides 41

6.4.1/ Objectives 41

6.4.2/ Scope 41

6.4.3/ IWM Context 41

6.5/ Research Project 4 - Control of Undesirable Vegetation in Amenity Plantings 41

6.5.1/ Objectives 41

6.5.2/ Scope 42

6.5.3/ IWM Context 42

6.6/ Research Project 5 - Integrated Control of Thistles 42

6.6.1/ Objective 42

6.6.2/ Scope 42

6.6.3/ IWM Context 42

6.7/ Research Project 6 - Biological Control of Thistles 42

6.7.1/ Objective 42

6.7.2/ Scope 43

6.7.3/ IWM Context 43

7/ References 43

List of Tables and Figures

Tables

1/ Potential IWM techniques for roadside weed and brush control in Ontario 7
2/ Additional IWM techniques for specific noxious weed control along Ontario roadways (in addition to techniques outlined in Table 1) 9
3/ Noxious weeds in Ontario under The Weed Control Act, 1988 10
4/ Shrubs, vines and forbs which occur on northeastern U.S. electricity ROW and roadsides to dominate a stand 12
5/ Definition of terms commonly used in discussion of basal herbicide application 26

Figures

1/ Segments across the highway right-of-way 2

1/ Introduction

1.1/ Background

This report was commissioned by the Ontario Ministry of Transportation (MTO) to review integrated weed management practices that could apply to roadside vegetation management and to identify areas which merit development and application for Ontario conditions. Undesirable vegetation on highway rights-of-way, both herbaceous and woody species, is that which presents safety concerns or is designated as noxious weeds or interferes with vigorous growth of landscape plantings.

The highway right-of-way (ROW) extends from the shoulder of the road to the outside property line or fenceline. It is comprised of physical engineering features including embankments, drainage courses and areas within interchanges and along the highway. Figure 1 provides a cross-section of a generalized divided highway from central median to property line.

The surface of the right-of-way is generally seeded to minimize surface erosion and to stabilize the physical design features of the highway.

A safety clear zone is maintained for 3 to 9 m (depending on the class of highway) to reduce off-road collisions and to maintain sight lines. As well, certain vegetation may result in snow drifting or ice forming on the road. Trees, shrubs, and other tall-growing vegetation that create hazards are removed and ground vegetation is mowed adjacent to the shoulder to provide emergency pull-off and snow storage areas.

The main objectives of the Ministry's current vegetation management program are:

1) *to achieve economies in roadside maintenance;*
2) *to maintain driver safety;*
3) *to control noxious weeds under the terms of the Weed Control Act;*
4) *to prevent drainage impairment;*
5) *to improve turf cover and aid in erosion control;*
6) *to maintain adequate snow storage areas;*
7) *to reduce icing of road surface;*
8) *to reduce snow drifting; and*
9) *to promote healthy growth of desirable vegetation [1].*

Vegetation management guidelines are detailed in the *Pesticide Spray Manual* [1] and *Maintenance Quality Standards M-300-1 to M-300-5* [2]. In general, vegetation management programs along

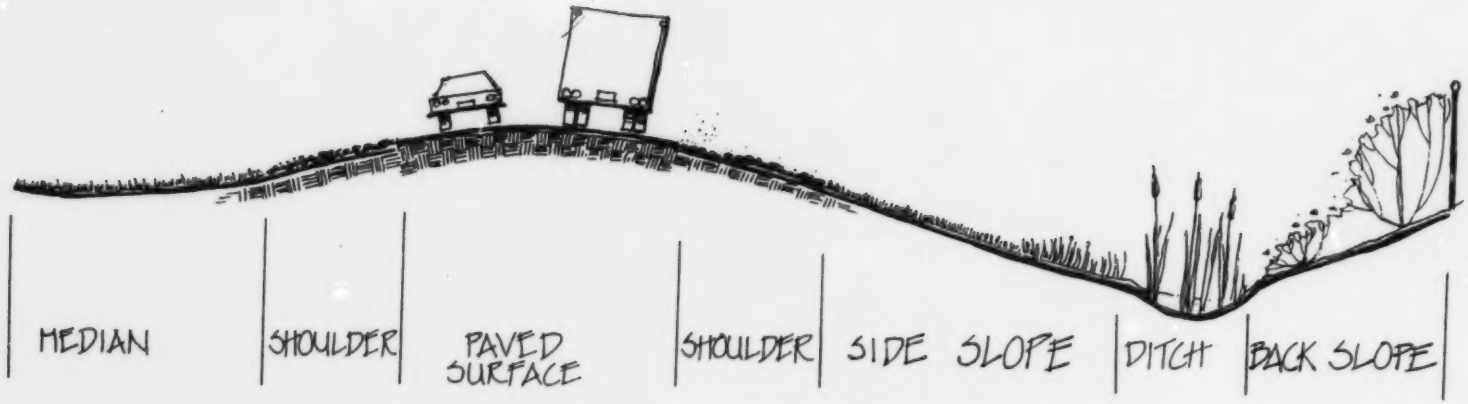

Figure 1/ Segments across the highway right-of-way

provincial highways focus on brush control and weed control in turf areas, depending on the part of the Province, as described by Dance [3]:

"Northern Ontario

Here, with the exception of Claybelt areas, the terrain is rocky; soils are generally shallow and forest flank the highways. The main challenge is to keep brush and regenerating trees from encroaching on highway rights-of-way...

Due to the nature of the vegetation to be controlled and the extensive areas involved, there is a reliance on chemical brush control. Usually a three to six year spray rotation is used...

Southern Ontario

This portion of Ontario is dominated by mixed or hardwood forest, where it has not been cleared for agricultural, industrial or residential use. Since soils are generally deeper and right-of-way geometry can be shaped, grass mixes are usually seeded following highway construction. Mowing occurs routinely and, because of the preponderance of agricultural and urban land uses, weed control is a significant issue. Weed control relies heavily upon broadcast herbicide spraying, but some spot and wick application is employed. In some cases, mowing provides a measure of weed control."

Natural regeneration has been encouraged in a number of southern districts and landscape plantings have been installed along rights-of-way in urban areas.

The Ministry's program of vegetation management was reviewed recently and new approaches such as integrated weed management techniques were proposed to address public concerns about pesticide use, continuing fiscal restraints, and interest in natural vegetation.

1.2/ Study Objectives

The objective of this study is to identify integrated vegetation management programs or their components which could be applied in Ontario highway rights-of-way and identify the research required to implement these programs. Specifically, the objectives were:

- to examine, through a review of the literature and activities in comparable agencies, integrated weed management (IWM) opportunities that could be applied to roadside vegetation management;
- to identify IWM program options and their components and indicate whether further research is required to develop or test these programs; and

- to outline specific research projects that would need to be undertaken to develop these programs.

2/ Study Approach

In addition to the staff of Ecological Services for Planning Ltd., the study team consisted of three scientific advisors from the University of Guelph: Dr. Jack Alex, Dept. of Environmental Biology, Dr. Glen Lumis, Dept. of Horticultural Science, and Dr. David Smith, Dept. of Botany, and two Ministry staff, Ms. Nancy Cain, Research and Development Branch, and Mr. Andy Stripnieks, Supervisor, Roadside Vegetation Management Unit. The client group and advisors were involved extensively in all pertinent stages of the study in order to ensure that the content and presentation of the report is consistent with the client group's objective.

As one of the aspects of the literature search, the DIALOG information-retrieval service was used to access the BIOSIS PREVIEWS, NTIS (National Technical Information Service) and the HRIS (Highway Research Information Service) subfile of the TRIS (Transportation Research Information Service) information databases.

Following review of the literature, information was arranged in tables and reviewed by the study team. Techniques were retained for further examination if it was felt that they had potential for evaluation in the Ontario context. Specific research projects were developed for vegetation management techniques which showed the most potential for incorporation into an IWM program for Ontario roadsides.

3/ Integrated Weed Management (IWM)

Integrated pest management (IPM) has been defined as:

> *"a pest control strategy based on the determination of an economic threshold that indicates when a pest population is approaching the level at which control measures are necessary to prevent a decline in net returns. In principle, IPM is an ecologically based strategy that relies on natural mortality factors, such as natural enemies, weather, and crop management, and seeks control tactics that disrupt these factors as little as possible"* [4].

Inherent to the principle of integrated weed management (IWM) is the use of two or more compatible techniques to achieve the pest control goal instead of relying on one technique such as chemical spraying which may also disrupt natural preditors or control agents. Techniques should be cost-efficient, effective, and reasonably straightforward to implement.

In agricultural situations, cultural practices are currently the most effective alternative to herbicides [4]. Cultivating, rotary hoeing, increasing the density of the crop plant to crowd out weeds, intercropping, timing of planting to give the crop a competitive advantage, and transplanting seedling crop plants to give them a head start on weeds are effective measures that are currently practiced. Many of these techniques are not practical or relevent to roadside situations which are more analogous to untilled pastures than to cultivated fields. Even here the analogy is weak since range managers often utilize fire and grazing animals to control weeds [5], techniques which have serious drawbacks for use in the Ontario roadside context. In many respects, roadside vegetation management has operational conditions which are unique from all other situations where vegetation management and weed control are practiced.

An integrated approach to roadside vegetation management embraces all forms of vegetation control including cultural practices, use of competitive vegetation, biological weed control, planting of allelopathic species, mechanical and physical vegetation control, and chemical vegetation control.

IWM along roadsides is concerned not only with the control of "noxious weeds" as defined by the Weed Control Act, but also with the control of tall growing woody and herbaceous species and the control of vegetation in special situations such as pavement cracks, concrete dividers, and landscape plantings. IWM may provide the Ministry with a more effective or economical vegetation management system in highway rights-of-way and may provide alternatives to current control practices. It may also provide a greater appreciation of the impact of each facet of right-of-way management on weed control.

Some agencies have implemented alternative vegetation management techniques. These include not only technical methods such as biological control, low-volume application equipment, new herbicide formulations and cultural control using low-growing vegetation, but also administrative and public relations methods such as employee training, public involvement programs, and public education. All of these techniques can be included in a broad definition of IWM since all are part of a multilevel approach to roadside vegetation management. This report will focus, however, on the technical aspects of integrated weed control.

4/ Literature Review

4.1/ Introduction

Integrated weed management techniques which could be applied to roadside vegetation are summarized in Tables 1 and 2. The rows list vegetation management problems or goals which have been identified by the study team while the columns list categories of IWM techniques. In Table 2, the problems are noxious weeds as designated by the Weed Control Act (Table 3) for which IWM techniques were identified. The boxes within each table list specific vegetation management techniques. Each technique is discussed in some detail in the accompanying text.

There is some overlap between sections because of the similar nature of some of the topics covered. For instance, there is substantial overlap between the "competitive vegetation" and "road design, construction and refurbishing" columns. However, these two areas have been divided so that "competitive vegetation" deals with plant species and communities whereas "road design, construction and refurbishing" addresses the establishment of roadside communities.

4.2/ Competitive Vegetation

4.2.1/ Control of Undesirable Vegetation and Maintenance of Vegetative Cover

4.2.1.1/ Plant Competition

Succession is the process by which a vegetation community gradually changes in composition and physical features over time until a relatively stable community is reached. This concept may have application to roadsides where the stable community has a suitable composition and height. There is, unfortunately, a great deal of controversy in the field of succession and there is no one widely accepted model of succession (see reviews 6, 7, and 8).

Regardless of the theoretical difficulties with succession, from a practical perspective the ideal scenario to reduce vegetation control costs along roadsides would be to establish stands of low-growing vegetation which would prevent the establishment of tall vegetation and noxious weeds and that would be stable for decades. Stable vegetation communities may be established, depending on the region, the species present in the soil seed bank and on adjacent land and on the number of years which the right-of-way has been chemically managed.

Two decades of selective-use herbicide management on a demonstration right-of-way within the Connecticut Arboretum has resulted in a number of relatively stable shrub communities and less stable herbaceous communities within the central hardwoods forest region [9]. Areas of continuous dense shrub

Table 1/ Potential IWM techniques for roadside weed and brush control in Ontario

POTENTIAL IWM TECHNIQUES							
Problem or Goal	**Examples**	**Control By Competitive Vegetation, Natural or Planted**	**Mechanical Control**	**Biological Control**	**Chemical Control**	**Combined Control Methods**	**Road Design & Construction, Refurbishing**
Brush Control	• woody pioneer species; shade intolerant, tree and shrub species	• stable plant communities of herbaceous species, grasses and low shrubs	• Hand-held torches • brush cutter on grader • prescribed burning	• encouraging grazing rodents • allelopathy	• alternative herbicides • wiper application • sprayer technology • herbicide injection • basal applications	• spray, cut, reseed • hand cutter with herbicide injection • cut stubble treatment	• stage seeding
Control of Tall Herbaceous Vegetation	• Herbaceous species such as sweet clover, reed grass	•grass and wildflower mixtures • legumes • competitive shrubs and vines	• mowing frequency and timing, type of mower • leaving cuttings on the ground	• allelopathy	• wiper application • sprayer technology		• stage seeding • drill seeding
Erosion Control (Maintenance of vegetation cover)	• annual weeds • shallow-rooted weeds • noxious weeds	• turf grasses • legumes			• *Cirsium arvense* control with hexazinone in crown vetch		• stage seeding • hardwood bark mulch after hydroseeding • drill seeding • preplant perennial weed control • fertilization at planting
Early Breakdown of Structures	• various weeds		• radiation: - Fresnel lens - infrared radiation				• application of soil residual herbicides under asphalt islands before they are capped

Table 1 (continued)/ Potential IWM techniques for roadside weed and brush control in Ontario

Problem or Goal	Examples	Control By Competitive Vegetation, Natural or Planted	Mechanical Control	Biological Control	Chemical Control	Combined Control Methods	Road Design & Construction, Refurbishing
Blocking of Ditches	• cattails • bulrushes • grasses • reed grass • purple loosestrife • willow, alders, and other brush		• dormant cutting • repeated cutting, timing		• wiper application		
Survival of Amenity Plantings	• various broadleaf weeds and grasses competing with amenity planting • Perennial weeds		• mulches		• chemical weed control		• mulches • preplant perennial weed control

Table 2/ Additional IWM techniques for specific noxious weed control along Ontario roadways (in addition to techniques outlined in Table 1)

POTENTIAL IWM TECHNIQUES					
Noxious Weed	**Competitive Vegetation**	**Mechanical Control**	**Biological Control**	**Chemical Control**	**Combined Control Method**
Wild Carrot		• timing of mowing	• not possible because of cultivated carrot	• various herbicides • possible tank mixes	
Goat's-Beard					
Milkweed	• Alfalfa hay		• yeast inhibiting germination of pollen • sublethal insects and diseases	• glyphosate • wiper or broadcast • timing of applications	
Ragweed		• adapted to mowing, trampling and grazing	• sublethal insects and diseases	• various herbicides	
Sow-Thistle			• possibly *Liriomyza sonchi* (insect)	• auxin-type herbicides	
Canada Thistle	• Alfalfa and forage grasses	• timing of mowing	• many insects, variable success • nematodes • goldfinch	• various herbicides • selective control may be possible in crown vetch	• combined program of mowing, herbicide use and fertilization
Nodding Thistle		• timing of mowing	• insects with variable success	• various herbicides • timing of applications	• combined program of herbicide use and fertilization

Table 3/ Noxious weeds in Ontario under The Weed Control Act, 1988[1]

Scientific Name	Common Name
Ambrosia spp.	Ragweed Species
Asclepias spp.	Milkweed Species
Barbarea spp.	Rocket, Yellow
Berberis vulgaris	Barberry, common
Carduus spp.	Thistle, Nodding, Species
Centaurea spp.	Knapweed Species
Cirsium arvense	Thistle, Canada
Cirsium vulgare	Thistle, Bull
Conium maculatum	Hemlock, Poison
Cuscuta spp.	Dodder Species
Daucus carota	Carrot, Wild
Euphorbia cyparissias	Spurge, Cypress
Euphorbia esula	Spurge, Leafty
Lathyrus turberosus	Vetchling, Tuberous
Onopordum acanthium	Thistle, Scotch
Panicum miliaceum (Black-seeded Biotype)	Proso Millet, Black-Seeded
Rhamnus cathartica	Buckthorn, European
Rhus radicans	Poison-Ivy
Solsola pestifer	Thistle, Russian
Sonchus spp.	Sow-Thistle, annual, Perennial
Sorghum halepense	Johnson Grass
Tragopogon spp.	Goat's-Beard Species
Tussilago farfara	Colt's-Foot

cover have resisted tree invasion for at least 15 years whereas areas dominated by grass cover have been quickly invaded by tree growth.

Along sections of a southeastern New York electrical utility right-of-way, various shrub communities have remained stable for 36 years [9,10,11]. The predominant vegetation was a cover of low shrubs and

[1] Government of Ontario, 1988. Weed Control Act, 1988. Dennis P. Caplice, Queen's Printer for Ontario, Toronto.

herbs averaging one-half meter in height, in which six species form over 90 percent of the vegetation: sweet fern *(Comptonia peregrina)* and hay-scented fern *(Dennstaedtia punctilobula)* are the most abundant; shield fern *(Dryopteris* spp.*)* forms a close third; blueberry *(Vaccinium* spp.*)*, huckleberry *(Gaylussacia* spp.*)* and sheep-laurel *(Kalmia angustifolia)* follow [10]. In central Pennsylvania, shrub types, especially huckleberry and low blueberry, are among the most stable plant covers and can be developed by the use of selective herbicides [12].

Witch-hazel *(Hamamelis virginiana)* thickets developed in abandoned pastures in East Haddam, Connecticut and have been stable for 40 years. Pure sheep-laurel clones in Marlborough, Connecticut have remained stable for several decades. Gray dogwood *(Cornus racemosa)* communities along hedgerows in two areas of Connecticut have been stable for at least two decades [9]. A stand of nannyberry *(Viburnum lentago)*, when initially studied in 1953 in Greenwich, Connecticut, had resisted tree invasion for 25 years [13]. After 45 years these plots were reported to be still clear of trees [9].

In a more recent study conducted along sections of rural roads in Wisconsin, American hazel *(Corylus americana)* and gray dogwood patches were relatively free of tree seedlings while those of staghorn sumac *(Rhus typhina)*, smooth sumac *(Rhus glabra)*, Canada plum *(Prunus nigra)* and wild plum *(Prunus americana)* often harboured a variety of tree seedlings [14].

At Aton Forest in Norfolk, Connecticut, several post-agricultural shrub communities, established prior to 1926, have exhibited remarkable stability for 47 years [9]. Among these communities are meadowsweet *(Spiraea alba)*, highbush blueberry, lowbush blueberry, arrowwood *(Viburnum dentatum)*, sweet fern, common juniper *(Juniperus communis)* and others.

Table 4 presents a list of shrubs, vines and herbs which occur in sufficient abundance on rights-of-way in the northeastern United States to form either a pure stand or to give character to the vegetation [15]. Some species, such as alder *(Alnus* spp.*)*, are aggressive weedy species on Ontario rights-of-way while others have agronomic concerns such as common barberry *(Berberis communis)* which is an alternate host for wheat rust and is classified as a noxious weed in Ontario. The only forbs observed to produce dense covers in the east are the goldenrods (*Solidago* spp.) [15]. Old-field communities which are often dominated by goldenrods, provide very good resistance against tree invasion even after 20 to 30 years[2].

While these species may act as deterrents to tree-seedling invasion, Egler found that all the species, except ferns, were being destroyed by herbicide programs to eliminate woody growth [15]. He described the general stages of the practice of blanket spraying herbicides along rights-of-way and the effect on

---

2 Personal communication with D. Smith, Professor of plant ecology, Dept. of Botany and Genetics, University of Guelph, Guelph, Ont.

Table 4/ Shrubs, vines and forbs which occur on northeastern U.S. electricity ROW and roadsides to dominate a stand [adapted from 15]

Shrubs and Woody Vines	
Alnus rugosa	Speckled Alder
Alnus serrulata	Southern Alder (Smooth Alder)
Amelanchier spp.	Serviceberry
Aronia arbutifolia	Red Chokeberry
Aronia melanocarpa	Black Chokeberry
Asimina triloba	Pawpaw
Berberis canadensis	American Barberry
Berberis vulgaris	Common Barberry
Bignonia capreolata	Crossvine
Callicarpa americana	French Mulberry
Campsis radicans	Trumpet creeper
Castanea pumila	Chinquapin
Ceanothus americanus	New Jersey Tea
Celastrus scandens	Climbing Bittersweet
Cephalanthus occidentalis	Buttonbush
Cercis canadensis	Redbud
Clethra tomentosa	White Alder
Clethra alnifolia	Pepperbush
Comptonia peregrina	Sweetfern
Cornus stolonifera (Cornus sericea)	Red-osier Dogwood
Cornus florida	Flowering Dogwood
Cornus rugosa	Round-leaved Dogwood
Cornus amomum	Silky Dogwood
Cornus racemosa	Grey Dogwood
Cornus alternifolia	Alternate-leaved Dogwood
Corylus americana	American Hazel
Corylus cornuta	Beaked Hazel
Crataegus spp.	Hawthorns
Diervilla lonicera	Bush Honeysuckle
Euonymus americana	Strawberrybush
Gaylussacia baccata	Black Huckleberry
Gaylussacia frondosa	Dangleberry
Gelsemium sempervirens	Yellow Jessamine
Hamamelis virginiana	Witch Hazel
Hydrangea arborescens	Wild Hydrangea
Hypericum spp.	Shrubby St. John's-wort
Ilex verticillata	Winterberry
Ilex glabra	Gallberrry
Ilex opaca	American Holly
Juniperus communis	Ground Juniper
Kalmia latifolia	Mountain Laurel
Kalmia angustifolia	Sheep Laurel
Lindera benzoin	Spicebrush
Lonicera japonica	Japanese Honeysuckle

Table 4 (continued)/ Shrubs, vines and forbs which occur on northeastern U.S. electricity ROW and roadsides to dominate a stand [adapted from 15]

Shrubs and Woody Vines	
Lyonia ligustrina	Maleberry
Myrica cerifera	Waxmyrtle
Parthenocissus quinquefolia	Virginia Creeper
Prunus virginiana	Chokecherry
Prunus allegheniensis	Alleghany Plum
Prunus americana	Wild Plum
Quercus illcifolia	Scrub Oak
Quercus prinoides	Chinquapin Oak
Rhododendron maximum	Rhododendron
Rhododendron nudiflorum	Pink Azalea
Rhododendron viscosum	White Swamp Azalea
Rhus aromatica	Fragrant Sumac
Rhus typhina	Staghorn Sumac
Rhus glabra	Smooth Sumac
Rhus copallina	Dwarf Sumac (Winged Sumac)
Rosa spp.	Wild Roses
Rubus odoratus	Purple-flowering Raspberry
Rubus idaeus	Wild Red Raspberry
Rubus allegheniensis	Common Blackberry
Rubus occidentalis	Black Raspberry
Salix bebbiana	Bebb's Willow
Salix humilis	Upland Willow
Salix sericea	Silky Willow
Salix cordata	Heart-leaved Willow
Salix discolor	Pussy Willow
Sambucus pubens	Red-berried Elder
Sambucus canadensis	American Elder
Serenoa repens	Palmetto
Smilax glauca	Greenbrier
Smilax rotundifolia	Round-leaved Greenbrier
Spiraea alba	Narrow-leaved Meadowsweet
Spiraea tomentosa	Hardhack (Steeplebush)
Spiraea latifolia	Broad-leaved Meadowsweet
Staphylea trifolia	Bladdernut
Symphoricarpos albus	Thin-leaved Snowberry
Symphoricarpos occidentalis	Western Snowberry
Symphoricarpos orbiculatus	Coralberry
Symplocos tinctoria	Sweetleaf
Vaccinium angustifolium	Low Blueberry
Vaccinium vacillans (Vaccinium pallidum)	Low Blueberry
Vaccinium corymbosum	High-bush Blueberry
Viburnum acerifolium	Maple-leaved Viburnum
Viburnum dentatum	Southern Arrowwood
Viburnum nudum	Possum Haw
Viburnum lentago	Nannyberry
Viburnum cassinoides	Wild Raisin
Viburnum rafinesquianum	Downy Arrowwood

Table 4 (continued)/ Shrubs, vines and forbs which occur on northeastern U.S. electricity ROW and roadsides to dominate a stand [adapted from 15]

Shrubs and Woody Vines	
Viburnum alnifolium	Hobblebush
Vitis spp.	Grapes
Ferns and Forbs	
Dennstaedtia punctilobula	Hayscented Fern
Onoclea sensibilis	Sensitive Fern
Pteridium aquilinum	Bracken
Solidago altissima	Tall Goldenrod
Solidago canadensis	Canada Goldenrod
Solidago graminifolia	Narrow-leaf Goldenrod
Solidago juncea	Early Goldenrod
Solidago rugosa	Rough Goldenrod
Solidago rugosa ssp. *aspera (Solidago aspera)*	Rough Goldenrod
Thelypteris noveboracensis	New York Fern

shrub species that are considered desirable due to their competitive ability against invading tree seedlings:

> *Stage One: Right-of-way Brush. In this condition, the vegetation is dominated by tree sprouts, resulting from many cycles of pre-1945 hand-cutting. Shrubs are less in bulk, but completely interspersed amongst the trees. Herbaceous grasses and forbs are few since these do not thrive in dense shade.*
>
> *Stage Two: Grass and Tree Sprouts. After repeated blanket-sprayings, ..., the desirable shrubs are both top-killed and root-killed. Forbs, which are herbicide-sensitive, are also killed. Trees are killed-to-ground, but not root killed; they resprout. The grasses ... are encouraged. ... Note that the most important components of the future desirable Vegetation - shrubs - are root killed. Many shrubs do not readily seed in, nor do they readily survive, if expensively planted by landscapers and horticulturists. The Vegetation Capital has been destroyed.*
>
> *Stage Three: Grass, Tree Sprouts and Tree Seedlings. Since further spraying is needed to control the resprouting trees, the "grassland" becomes still more thin and more open. Some of the old sprout root systems may be killed, whereas the rootsuckering trees, like aspen, ailanthus, and sassafras are only encouraged to be more prolific. Furthermore, the "grassland" is now opened to reinvasion by dense masses of tree seedlings, such as the pines and the birches. Herein lies the utter foolishness of the whole procedure. These new generations of dense seedlings - I have observed them in many parts of the country - actually inhibit any minor development of shrubs that might otherwise occur,*

and limit grass growth. Soon the right-of-way has more undesirable brush than it had before the first spraying.

Stage Four: The Tree Seedling - "grassland" Cycle. The land manager is now locked into an unfortunate situation, ... The new rapidly growing tree seedlings are so dense that they require blanket-spraying, which in turn produces thin grasslands, which in turn invites new dense masses of tree seedlings. Etc., ad inf. This situation was predictable, and was predicted by ecologists years ago, ...

The only way out of this predicament is - not to plant shrubs - but to do nothing, for a considerable number of years ..., until the trees are as tall as can be tolerated. By that time, they will have thinned themselves out considerably, probably to one percent of the individuals that had existed when they were two or three years old. Furthermore, rabbits, deer and elk may be postponing the situation (to the advantage of the utility company, ...). When these new saplings have reached a height of 8-15 feet, various shrubs will be found to be reappearing below the trees. It is now time selectively to remove the trees, carefully preserving the shrubs. Such removal can be accomplished by either chemical or physical techniques that have already been scientifically successful [11].

Similar recommendations have been given elsewhere [9,16]. In a three year experiment on an electrical utility right-of-way in northern Ontario, it was found that, in general terms, chemical brush control was imperfect because it reverses succession to a stage conducive to tree establishment [16]. Residual species capable of sprouting after cutting and after spraying with picloram plus 2, 4-D (Tordon 101) were black spruce *(Picea mariana)*, red maple *(Acer rubrum)*, beaked hazel *(Corylus cornuta)*, witherod *(Viburnum cassinoides)*, speckled alder *(Alnus rugosa)*, mountain holly *(Nemopanthus mucronatus)* and shadbush *(Amelanchier* spp.). Adventive species, i.e. those capable of invading by seed dispersal, included: black spruce, red maple, pin cherry *(Prunus pensylvanica)*, paper birch *(Betula papyrifera)*, silky willow *(Salix sericea)*, pussy willow *(Salix discolor)*, balsam fir *(Abies balsamea)* and tamarack *(Larix laricina)*.

Ideal management would hold succession at a different (later but not climax stage) stage, where many factors work against tree regeneration. Low growing shrubs can control regeneration of unwanted species by competition, by favouring seed-eating animals, and by maintaining a thick litter layer [16]. Maintenance of a vegetation layer was found to be essential, not only to renew the litter layer, but also to lower its temperature so that it is not decomposed as quickly. The litter layer acts to suppress tree invasion and may ensure the persistence of picloram in the upper level of the soil. Piling brushwood to

create habitat for small herbivores which may act to control adventive tree species has been suggested [16].

4.2.1.2/ Allelopathy

Allelopathy refers to the direct or indirect effects of one plant on another through production of chemical compounds that are released into the environment [17]. Although effects on the recipient plant may be positive or negative, allelopathy is generally thought as having detrimental influences on the recipient plant [18]. Proof of allelopathy requires rigorous protocols and there are many instances of alleged allelopathy that still require considerably more proof. The methodology of allelopathic research, as well as the mechanisms of allelopathy have been reviewed [19].

The allelochemicals have been identified for several common weeds including quackgrass *(Agropyron repens)*, yellow-nut sedge *(Cyperus esculentus)*, kochia *(Kochia scoparia)*, ragweed *(Ambrosia* spp.*)* and Johnson grass *(Sorghum halepense)* [19,20]. Several other common weeds and native plants exhibited allelopathic properties, although the chemicals responsible have not been identified. These included Canada thistle *(Cirsium arvense)*, milkweed *(Asclepias syriaca)*, wild carrot *(Daucus carota)*, asters *(Aster* spp.*)*, goldenrods, bracken fern *(Pteridium aquilinum)*, hay-scented fern, New York fern *(Thelypteris noveboracensis)*, short husk grass *(Brachyelytrum erectum)*, wild oat grass *(Danthonia* spp.*)*, club moss *(Lycopodium* spp.*)*, low-bush and high-bush blueberry, barberry, maple leaf viburnum *(Viburnum acerifolium)*, hobble bush *(Viburnum alnifolium)*, witherod, sweet fern and American cranberry bush *(Viburnum trilobum)* [21,22]. Certain crops plants such as rye *(Secale cereale)*, barley, sorghums *(Sorghum* spp.*)*, wheat *(Triticum aestivum)*, oats *(Avena* spp.*)*, timothy and tall fescue *(Festuca arundinacea)* have also demonstrated allelopathic properties [17,19,23,24]. Tall fescue is often planted along roadsides.

Greater understanding of chemical ecology, including allelopathy, may well lead to the development of more economical and environmentally sound right-of-way maintenance practices [18]. While many of the potential benefits of allelopathy are yet to be discovered, many native shrubs that exhibit allelopathic properties, such as the ones listed above, can be encouraged to spread on a right-of-way with selective herbicide applications [18]. As mentioned previously, when used on appropriate sites these plants could establish stable communities that inhibit the encroachment of undesirable species for extended periods of time. Developing an inventory of desirable species in a particular section of right-of-way and recording soil and climatic conditions will provide information that will be useful in establishing such plant communities [18].

Wildflowers plantings in parts of the United States have provided visually pleasing, low maintenance roadside communities. Wildflower programs have generally been most successful in midwestern and

southwestern states whose native vegetation is prairie grasslands [25,26,27,28,29]. Wildflower plantings can be successful in the northeastern states although naturalization, as a roadside philosophy or objective, may be inappropriate if the volunteer species are trees that become so tall as to create potential traffic hazards along the roadside [30,31]. A recent review of existing roadside wildflower programs indicates that weed invasion is a major concern for wildflower plantings in Ontario especially during establishment [32].

4.2.1.3/ Grasses

Low maintenance turf grass mixtures are seeded on roadsides following construction and continue to be the major roadside vegetation treatment, particularly in southern Ontario. Appropriate cultivar selection is an important component of an IWM program to provide vigorous, competitive right-of-way turf cover. In the recent report on the Ministry's vegetation management program, a review of the standard seed mix is recommended in light of research on competitive, low-growing and stress-tolerant grasses [3]. The Illinois Department of Transportation has developed a salt-resistant grass blend for use on roadside areas within 25 feet from the edge of the pavement [33]. Included in this seed mixture of Dawson red fescue *(Festuca rubra* 'Dawson'*)* and hard fescue *(Festuca longifolia)*, is Fults alkali grass *(Puccinnella distans)*, a salt grass discovered growing along the Chicago expressways in the early 1970s. They have also experimented with native prairie grasses, including buffalo grass *(Buchloe dactyloides)* which thrives on dry, sandy soil. Once established it spreads to form a low, tough turf that requires only occasional mowing due to its low natural height (15 cm). Buffalo grass, which is an important constituent of the short-grass prairies, can tolerate extreme temperatures and drought [33].

Native dryland grasses usually take several years to establish a satisfactory stand but irrigation may result in faster establishment. In Idaho, shoulder-slope grass mixes are being developed with emphasis on low-growing, fire-resistant traits, and grasses that are sod formers as opposed to bunch grasses [34]. In northern Idaho in areas that have more than 380 mm of annual precipitation, durar hard fescue is used. This is part of a program to plant the "right grasses in the right places" along roadsides [30].

In New Jersey, several varieties of grasses have been tested for roadside use [30,35,36]. A new mixture composed of equal portions of Fortress creeping red fescue *(Festuca rubra* var. *rubra* 'Fortress'*)*, Banner Chewings fescue *(Festuca rubra* var. *commutata)* and 'Kenblue' Kentucky bluegrass *(Poa pratensis* 'Kenblue'*)* required less mowing and had a better appearance than a mixture comprised of 20% Kentucky bluegrass, 35% red fescue, 20% 'Kentucky 31' tall fescue, 10% redtop *(Agrostis gigantea)*, 10% perennial ryegrass *(Lolium perenne* var. *perenne)* and 5% white clover [35]. However, since the new mixture was slower to establish, it was felt that a cultivar such as Manhattan ryegrass *(Lolium perenne* 'Manhattan'*)* should be added to improve initial establishment and germination of the mixture.

Only a limited amount of testing of new grass cultivars on roadsides and other minimum maintenance situations has been done [35]. Kentucky bluegrass cultivars such as 'Kenblue,' 'Park,' 'Troy,' 'Delta,' 'Arboretum' and 'South Dakota' tolerated the stresses of low maintenance and persisted better than the low growing, dense, and compact types developed for fine turf use [36].

The brightest development in the area of roadside mixtures are the hard fescues [36]. Although less well known than other fescues, hard fescue cultivars such as 'Biljart,' 'Scaldis,' 'Reliant' and 'Spartan' are dense, low growing and have the excellent summer green colour compared to other cool-season utility grasses, particularly under low maintenance regimes [30,36]. Hard fescues require minimum mowing, tolerate low fertility and low soil moisture and, once established, their dense turf effectively excludes most weed encroachment.

Ouell feels that superior grass cultivars for roadside use do exist although there is need for more testing [36]. He suggests that buyers should not accept seed of "Kentucky bluegrass," "Perennial ryegrass" or "tall fescue" without a cultivar name since some cultivars may have superior characteristics for a particular site, use, and management regime.

In Massachusetts, a grass mixture containing 50% creeping red fescue, 20% domestic ryegrass, 5% redtop and 25% Kentucky bluegrass for rights-of-way is recommended [37]. Established grasses deteriorated if they were not limed and fertilized regularly [37]. On median areas, good-quality turf that had not received lime or fertilizer for more than five years continued to produce satisfactory cover but was showing signs of thinning and weed encroachment.

In Quebec, applications of 2,4-D, 2,4,5-T and sodium trichloroacetate suppressed woody plant growth to the advantage of herbs, mostly grasses, which invaded the corridors and created rather stable artificial communities [38]. In contrast to other studies, it was suggested that seeding and fertilization following brush removal to encourage grasses should be studied since the establishment of these artificially stable prairies would compete with adventive tree species.

In Maine, a newly developed, fast-establishing cool season ryegrass, (*Lolium perenne* 'Aroostook'), is being added to seed mixes as a nurse grass during early spring and late fall applications [39].

4.2.1.4/ Establishment of Herbaceous Vegetation

On declining sites in Maine, legume species, such as rose acacia (*Robinia hispida*), crown vetch (*Coronilla varia*) and bird's-foot trefoil (*Lotus corniculatus*), have been used. These species provided a dependable ground cover on problem grassland sites and reduced brush invasion into the roadside safety clear zone [39].

Leguminous species recommended for seeding in Massachusetts included flat pea *(Lathyrus sylvestris)*, goat's rue *(Galega officinalis)*, false blue indigo *(Baptisia australis)*, bird vetch *(Vicia cracca)*, Cicer milk vetch *(Astragalus cicer)*, bristly locust *(Robinia fertilis)* and Dyer's greenweed *(Genista tinctoria)* [37]. Compatible nurse crops included creeping red fescue, perennial ryegrass and 'Kentucky 31' tall fescue. Creeping red fescue, tall fescue, domestic ryegrass *(Lolium* spp.*)*, redtop, and white or ladino clover *(Trifolium repens)* seeded at 95 kg/ha was a successful mixture.

4.2.2/ Competitive Control of Milkweed and Thistles

Alfalfa hay meadows were the most effective crop and cultural practice for the eradication or control of milkweed in northern Michigan [40]. Seeding fields and roadsides with competitive vegetation has been found to effectively prevent or reduce thistle populations [41]. Competitive crops, especially alfalfa *(Medicago sativa)* and forage grasses, have been used to control milkweed infestations [42].

Increases in interspecific competition have been found to reduce nodding thistle (*Carduus nutans*) populations [43]. In Nebraska pastures, competition reduced plant size and flower number and increased mortality of nodding thistle [44].

4.3/ Mechanical Control

4.3.1/ Brush Control and Mowing

Involvement in mechanical vegetation control methods such as mowing has decreased in almost every state in the U.S. because of increasing labour costs [45]. This has been the case in Ontario as well. In many places the techniques themselves have been fine-tuned in order to make them more efficient. In Oregon, for instance, mowers which are three times as wide as regular tractor mowers have been used [46]. In Clark County, Alabama, robot brush cutters have been mounted to graders allowing two jobs to be done at once [47].

In New Hampshire, hand-held kerosene torches were tested for woody vegetation control along a powerline ROW [48]. The intense heat of the flame killed the cambium, thereby girdling the stem. First-year results indicated that the torch was about as effective as herbicides in treating species of woody vegetation including white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), red maple, red oak (*Quercus rubra*) and white ash (*Fraxinus americana*). While resprouting was often delayed until the second growing season, it could be delayed longer by applying heat for a longer period and treating the stems closer to the ground. Treatment required one to two man-hours per acre, indicating that costs were about one-fifth the cost of comparable manual herbicide applications.

At least one state, Minnesota, practices prescribed burning along sections of its roadsides [26,49]. This technique, while effective at suppressing brush, requires special training and is done in conjunction with the Department of Natural Resources.

In many places mowing heights have been increased while mowing frequency has been reduced, often in conjunction with the use of plant growth regulators. Missouri has raised its mowing height from 10 to 20 cm [50]. It has been found that longer grass forms a strong turf that helps choke out weeds and reduces mowing needs [28,29]. In Missouri, mowing is delayed until later in the season (September 15) to allow desirable native vegetation to flower [28]. In New Mexico, vegetation is mowed in late September when it reaches 45 cm along highways and 60 cm along other roads [51].

4.3.2/ Mechanical Weed Control Along Structures

Several liquified petroleum gas infrared weeders are available on the European market for weed control in row crops [52]. For efficient plant destruction, an energy emitter is required which produces a high intensity at a wavelength which is absorbed, rather than reflected or transmitted, by the plant tissues. Another technique uses a Fresnel lens which focuses radiant energy and kills weed seeds in the soil [53]. Both these techniques, while still in early stages of development may show promise for weed control along road shoulders or concrete areas.

4.3.3/ Mechanical Weed Control in Ditches

In both field and container situations, cattails *(Typha latifolia* and *Typha angustifolia)* responded differently if cut above or below the water line [54]. Three cuts below water during the growing season were sufficient to kill nearly all the underwater biomass. Similar cuts above water reduced the total biomass compared with uncut plants, but much of the underwater biomass remained healthy and able to regenerate. Plants cut above the water line were able to regenerate because the above water plant parts translocate oxygen to the roots and rhizomes.

Dead shoots present during the dormant season may also be important in the transfer of oxygen to roots and rhizomes. Cutting or bending dead shoots (mid-October to mid-April in the Chesapeake Bay area) reduced maximum above-ground biomass and plant height the following season, especially if done at the beginning of the dormant season [55]. Cutting the dead shoots also reduced the density of live shoots in the following growing season, while bending increased it.

In Minnesota, biomass and nutrient content is maximum in the leaves of cattails and minimum in the rhizomes in midsummer (late July to early August) [56]. Removal of top growth would likely be most stressful to the plant at this time.

4.3.4/ Mechanical Control of Noxious Weeds

Wild Carrot

The flowering stage of wild carrot is most vulnerable to cutting [57]. The more frequent the cutting, the smaller the plant and the lower the reproductive capacity. A single mowing late in summer was also found to be an effective control [58].

Ragweed

Ragweed (*Ambrosia artemisifolia)* was able to adapt to mowing, trampling and grazing [59]. In Ottawa, plants cut in July developed several new stems and flowered about 10 days later than adjacent uncut plants. Several cuttings, therefore, were required in August to prevent flowering and seed development.

Canada Thistle

Repeated mowing of Canada thistle will weaken surviving stems, prevent seeding and disrupt the production and transport of photosynthate from above ground shoots to roots [41,42].

Disruption of accumulation of root reserves over the growing season leaves the root system less able to survive winter and initiate new shoots the following growing season. In a study conducted in Ohio, thistle stands cut more than twice per growing season at monthly intervals were found to have almost disappeared by the end of the fourth season [41]. Since the low point in root reserves is reached in prebud stage, the maximum disruptive effect may be achieved when mowed at that stage of growth.

In order to prevent seed formation, stems must be mowed by 8-10 days after flowering. If plants are cut after this, they will still be capable of producing seed even if severed from the root system [41].

Nodding Thistles

Mowing nodding thistle (*Carduus nutans)* within two days of opening of the first terminal flowers in a plant population, eliminated the production of viable seed from all mowed stalks [60]. Those mowed after six days produced a significant quantity of viable seeds and those mowed after 11 days produced an amount of viable seed similar to unmowed plants. More than a single mowing per season was required for effective control because of the large differences in plant maturity in natural populations. Mowing prior to flower opening allowed regrowth to occur and viable seeds to be produced.

4.4/ Biological Control

Biological control of weeds has been described as the deliberate use of natural enemies to suppress the growth or reduce the population of a weed species [61]. Insects, mites, plant pathogens, and aquatic and

terrestrial herbivores have all been used as biotic agents in biological weed control programs. Numerous review articles describe the principles, the methodology, and the progress of biological weed control [62].

Cattails

Although several insects and fungus attack cattail, no biocontrol programs exist [63].

Purple Loosestrife

There is a program presently underway in the state of New York for the biological control of purple loosestrife[3] .

Wild Carrot

Wild carrot is not a candidate for biological control since predators would affect the cultivated carrot as well [57].

Milkweed

Although several insects and disease organisms attack common milkweed, none has been credited with any great reduction in either density or incidence [64]. Recently, strains of yeast, alone or in combination with moulds and bacteria, were found to inhibit pollen germination in milkweed which ultimately prevented the formation of seeds [65,66,67]. This discovery may have practical applications for future biological control of milkweed.

Ragweed and Sow Thistle

Several insects and disease organisms are known to attack the ragweeds and the sow-thistles but none have proven very effective in reducing weed populations [59,68,69]. Permission has been granted by the Canadian Biocontrol of Weeds Committee to release *Liriomyza sonchi*, a leaf-mining agromyzid (insect), for sow thistle control evaluations in Canada [70].

Thistle Species

Several insects have been studied for their potential as biological control of Canada thistle. In Canada, these included: *Altica carduorum* (flea beetle), *Ceutorhynchus litura* (stem-mining weevil), *Urophora cardui* (gall fly) and *Lema cyanella* (leaf-feeding beetle) [42,62,71,72]. These have either not become established in field situations or have not provided effective control. However, *U. cardui* has spread in Ontario and may have stressed the plant populations to some degree [73]. In Pitkin County, Colorado, roadside managers are working with several species that feed on Canada thistle,

[3] Personal communication with J. Alex, Professor of weed biology, Dept. of Environmental Biology, University of Guelph, Guelph, Ont.

such as painted lady butterfly (*Vanessa* sp.) larvae, to artificially increase numbers for mass release in infested areas [74]. *Rhinocyllus conicus* (thistle-head weevil) which has been released for the control of nodding thistle, has also attacked Canada thistle [71,75], but damages to the plant have not been extensive [76]. A strain of *Sclerotinia sclerotiorum*, a fungus, has been a promising biocontrol agent for several weeds including Canada Thistle [77]. Also, goldfinches (*Carduelis* sp.) are known to feed avidly on thistle seeds.

Two insect species, *Rhinocyllus conicus* and *Trichosirocalus horridus*, have been studied in Canada for the biological control of nodding thistle (*Carduus nutans)* and plumeless thistle (*Carduus acanthoides).* The larvae of *R. conicus* feeds by mining the thistle flower stalk (both the receptacle and peduncle) with the net result being a reduction in seed production. This weevil may reduce seed production enough to reduce the density of new thistle plants. This could allow the entry of competing vegetation which might eventually displace the thistle. Control of nodding thistle in Virginia and Saskatchewan has been achieved by a combination of *R. conicus* and competition from other plants [76]. *R. conicus* has only a slight effect on plumeless thistle seed production.

There have been differences reported in the degree of effect on seed reproduction. In Saskatchewan, most of the large *C. nutans* rosettes were attacked in the spring, but they survived to produce seed [76]. In Virginia, when healthy and vigorous rosettes were infested, many recovered and reached maturity [78]. However, when smaller rosettes of nodding and plumeless thistle were attacked, a reduction in the number of heads and seeds per plant resulted. While Kok concluded that release of *T. horridus* should result in a decrease in thistle populations, Harris disagreed [76,78].

R. conicus and *T. horridus* were released along Maryland and Pennsylvania roadsides to study their effects on control of *Carduus* thistles in crown vetch [79]. These biological control programs, in Pennsylvania at least, have been abandoned because of their ineffectiveness[4] .

The fungus *Puccinia carduorum* Jacky may stress thistles without interfering with activity of insects introduced for biological control [80].

4.5/ Chemical Control

It should be noted that some of the herbicide treatments or tank mixes mentioned in this section may not be registered for use in Ontario.

[4] Personal communication with C. Bossarman, Pennsylvania Dept. of Transportation.

4.5.1/ Application Technology

The effectiveness of certain herbicides is increased when they are applied in oil instead of water [88]. It is only possible to spray paraffinic oils with electrostatic, mechanical or pneumatic spray systems. Conventional hydraulic spray nozzles, because of inadequate production of spray droplets and spray distribution, cannot be used for this purpose [82].

Other herbicide methods can be used to control tall weeds in stands of shorter, more desirable vegetation. As well as using low amounts of herbicide, such techniques have no drift problems. In recycling sprayers, solid stream nozzles are directed horizontally, so that spray which is not intercepted by tall weeds is collected on a foam pad and recycled [81]. This sprayer has been used to control tall weeds such as Johnsongrass, wild oats and milkweed with glyphosate.

Another system is the rope wick applicator consisting of overlapping sections of braided nylon rope, connected to a reservoir of herbicide spray [81]. The rope must be designed to sufficiently wet the weeds but not allow the chemical to drip elsewhere.

Similar to the rope wick applicator are the carpet or roller applicators. Horizontal rollers with various absorbent surfaces are constantly imbibed with herbicide and carried at a sufficient height over desirable vegetation so that only tall weeds are contacted. Several advantages to the application of herbicides using roller applicators include: efficacy, efficiency, no drift, public acceptance, minimizes the amount of herbicide needed and year-round equipment use [89]. This technique has been used to control brush and tall herbaceous weeds in pasture situations [101,102,103].

In northeastern Saskatchewan, adequate initial damage to aspen, balsam poplar and willow was obtained with roller applied glyphosate at concentration of 1.6% a.i. or 0.60% and 0.07% a.i. of 2,4-D plus picloram [91]. However, one year after treatment the glyphosate treated areas had better brush control than those treated with 2,4-D alone or in combination with picloram, except when these two latter herbicides were applied at high concentrations.

Lower herbicide concentrations (glyphosate 0.18% a.i., or 0.2% 2,4-D plus 0.02% picloram) required three or four passes with the roller through the brush to cause equal damage as one pass with herbicide of three times the strength [92]. In Texas, the use of a scraper ahead of the roller removed bark from stems, increased the effectiveness of picloram against some range shrubs but did not increase the effectiveness of glyphosate [104]. The scraper also reduced the herbicide loss by runoff down the stems.

Efficacy of roller-applied herbicides may be influenced by the timing of the application. In controlling a variety of woody species along an Indiana right-of-way, growing season applications of a number of

brush herbicides resulted in 60% to 80% control and dormant season applications gave 100% control of the same species [89]. In North Dakota, fall applications of roller-applied picloram tended to provide better control of leafy spurge *(Euphorbia esula)* than spring applications.

4.5.2/ Chemical Control of Brush

4.5.2.1/ Basal Techniques

Basal herbicide applications provided directed, selective means for removing undesirable woody vegetation without affecting desirable woody and herbaceous species [94]. Several alternatives to conventional basal bark and cut surface herbicidal applications have been developed. These include thinline, low volume, low volume banding and streamline. Table 5 defines all of these basal application techniques and compares the conventional techniques with the others.

Low volume basal applications, including thinline and streamline, offer numerous advantages over conventional basal techniques which require larger quantities of oil-based diluents. These include:

1. Potential savings in carrier/penetrant;
2. Increased labour efficiency since applicator makes fewer refill trips;
3. Application has less odour since less oil-based carrier is applied per acre; and
4. Less oil-based carrier is introduced into the environment [94].

High overall rates of success have been obtained in brush control using low volume basal and thinline herbicide application [94,95,96,97,98]. Likewise, streamline applications have been shown to be as effective as conventional basal applications [97,99,100].

Conventional carriers such as diesel fuel create several problems because of their high volatility, their strong odour and problem of premature deterioration of rubber gaskets in application equipment. Refined mineral oil can serve as an alternative to currently used carriers [101]. Applications of 80% mineral oil in combination with various mixtures of brush herbicides provided excellent control of pin cherry, locust, sassafras, white oak, red maple, white pine, staghorn sumac and ailanthus.

4.5.2.2/ Broadcast Applications

Tests in Virginia showed that dormant season broadcast applications appear to be a viable alternative for brush control [102]. Triclopyr (Garlon 4) was effective when applied as a dormant application but timing was found to be very important; late fall and early spring treatments yielded the best results. In Pennsylvania, early April applications of triclopyr controlled all contacted portions of several woody species including oak, red maple, honeysuckle and dogwood [103].

Table 5/ Definition of terms commonly used in discussion of basal herbicide application

Method	Definition	Application	Rate	Carrier	Use
Conventional	Application of 1-3 percent herbicide in oil to the entire circumference of the lower 12-15" of treated stem.	With backpack of low pressure sprayer, stems are treated by thorough wetting to runoff to a height of 12-15" above the ground. For suckering species ground under the target stem should be sprayed to cover root suckers.	20-80 gal mixture/acre 1-3% (v/v) herbicide in oil	Diesel, #1 or #2 fuel oil, kerosene	Control of woody plants with stems 8" and less. Effective for both growing season and dormant application on resprouts or single stems.
Thinline	Application of undiluted herbicide in a thin stream (usually 0.0005 nozzle orifice) to the entire circumference of stems.	Application of the thin stream of herbicide is directed horizontally around the stem circumference, at or about 6" above the ground.	2-14 ml per stem	None	Control of woody plants 4" and less. Can be applied both dormant and during the growing season.
Low Volume	Application of herbicide mixed with oil or diluent to the entire circumference of stems on the lower 12-15" above ground line.	Using a backpack sprayer, the lower 12-15" of stem circumference is treated with herbicide mixture for thorough coverage, but not to the point of runoff. Root collar coverage is critical.	2-8 gal mixture/acre 20-30% herbicide	Diesel, kerosene, surfactant, penetrant	Control of woody plants with stems less than 6" diameter in growing and dormant season applications.
Low Volume Banding	Application of herbicide mixed in diesel, kerosene, or other approved diluent (50:50) to all sides of a stem in a 3-4" wide band at a height up to 3 feet above ground.	Mixture of 50:50 herbicide/carrier is applied as a 3-4" wide mist spray band up to 3 feet above ground line using a backpack sprayer and a solid cone nozzle.	1-4 gal mixture/acre	Diesel, kerosene, approved diluent	Control of woody plants with stems less than 6" diameter in growing and dormant season applications.

Table 5 (continued)/ Definition of terms commonly used in discussion of basal herbicide application

Method	Definition	Application	Rate	Carrier	Use
Streamline	Application of herbicide mixed with diesel and surfactant (20:70:10) to 1-2 sides of stem at ground level of where juvenile bark forms.	Mixture is applied in a straight stream in a narrow bank (0.0002 straight stream nozzle) to one or two sides of a target stem. Target application of the band of herbicide mixture is ground level up to 6". If mature bark has formed, treatment should be made at the height of juvenile bark.	2-5 ml per stem, 20% herbicide: 70% diesel: 10% penetrant, 1-1.5 gal mixture/acre	Diesel, surfactant/ penetrant	Control of woody plants with stems less than 4" diameter. Can be used in dormant or growing season applications.

From Hendler et al., 1987 [97]

4.5.3/ Chemical Control of Weeds in Ditches

Amitrole and dalapon were effective as foliar sprays for cattail control [104]. In Washington, a trial in a shallow drainage ditch densely infested (44 shoots/m^2) with common cattail, found that best control was achieved with glyphosate applied to mature cattail about a week before the first autumn frost (96% stand reduction) [105]. Treatments applied when cattail was in mid full bloom (early July) were much less effective than when applied later in the season (August-September). Amitrole and ammonium thiocyanate were as effective as glyphosate (92% stand reduction). The year following treatment, redtop *(Agrostis alba)* and horsetail rush *(Equisetum* spp.*)* dominated many of the treated plots.

4.5.4/ Chemical Control in Landscape Plantings

An effective technique for controlling weeds in landscape plantings is treatment with a non-residual herbicide prior to planting. Such a treatment decreases the amount of weed control required after the amenity plants are in the ground, thus reducing maintenance and reducing the risk of herbicide damage to desirable plants. Post-planting chemical weed control can be combined with mulch application for long-term weed control in landscape plantings. The chemical used must be selective for the amenity plants.

4.5.5/ Chemical Control of Noxious Weeds

Wild Carrot

Young wild carrot plants are especially susceptible to 2,4-D when plants are 4 to 6 inches high [106]. A tank mix of dicamba, 2,4-D, chlorsulfuron, and a non-ionic surfactant, applied in early spring provided excellent control of wild carrot seedlings and rosettes of second-year plants [107].

Milkweed

Glyphosate provided satisfactory control (70% or better) of common milkweed when applied at the early or late bud growth stage [108]. A roller applicator provided as good control as broadcast spray applications and used only 10-20% as much herbicide.

Amitrole at 4.5 kg/ha appeared to control common milkweed better when applied at the late bud stage (69%) than when applied at the early bud growth stage (59%) [64]. The early application (25 June in southcentral Ontario) of either glyphosate or amitrole, provided better control of common milkweed the following year than did later applications (30 July or 30 August).

Herbicides such as 2,4-D, 2,4-D plus mecoprop plus dicamba (Kil-mor), MCPA and dicamba destroy the top growth of milkweed without appreciably affecting the root system. This leads to vigorous growth of adventitious root buds [64].

Ragweed

Control of ragweed is most effective when herbicide treatments of 2,4-D, MCPA or mecoprop are made during the months of June, July and August [68].

Sow Thistle

Perennial sow-thistle *(Sonchus arvensis)* is more difficult to control than the annual species. Auxin-type herbicides are most effective for perennial sow thistle control [69].

In general, 2,4-D and dicamba were more effective than glyphosate in reducing perennial sow thistle density one year after treatment [109]. Likewise, fall applied glyphosate generally was less effective than fall applied auxin-type herbicides [69].

Early applications (rosette stage) of 2,4-D and dicamba were more effective in reducing shoot density one year after treatment than were late applications (bud stage) [109]. MCPA and 2,4-D provided greater reduction in root weight when applied at the late rosette stage compared to the late bud stage [110].

Canada Thistle

Canada thistle can be controlled with a variety of different herbicides, however, complete kill of its spreading perennial root system is hard to achieve [111,112].

Treatments of atrazine, clopyralid or hexazinone gave total root kill of Canada thistle in crown vetch, if applied in early August [113]. Applications in mid-June gave regrowth by the end of July.

Hexazinone applied in crown vetch in September appeared to provide some Canada thistle control into the following summer [114].

Nodding Thistles

Herbicides, such as 2,4-D ester, 2,4-D amine, dicamba and picloram were generally found to be most effective on nodding thistle just prior to flowering [60]. Nodding and plumeless thistles are most susceptible to hormone-like herbicides applied during periods of active growth of the seedlings or rosettes, that is, during the spring or fall [43].

Nodding thistle becomes less susceptible to herbicides after stalk elongation following which flowering and seed production occurred in a considerable number of plants, even at higher doses [115]. Of several herbicides tested, picloram was found to be the most effective. However, because of the great potential seed production of nodding thistle, a second year application of herbicides was considered necessary.

4.6/ Combined Control Methods

It should be noted that some of the herbicide treatments or tank mixes mentioned in this section may not be registered for use in Ontario.

4.6.1/ Brush Control

Picloram and triclopyr herbicides can be used effectively to control resprouting of brush stubble [116]. Tank mixtures of picloram and triclopyr herbicides show greater activity on hard-to-kill species such as red oak than either compound used separately. Control is best when herbicides are applied within 1 or 2 days after mowing compared to several weeks or months. The overall goal of the cut stubble application is to reduce the brush density to a point where subsequent mechanical brush removal can be delayed and the right-of-way can be effectively and economically maintained through selective chemical brush control programs [116].

Cut stubble applications of picloram and triclopyr provided acceptable sprout control of various tree species in Kansas but foxtail grass and giant ragweed quickly invaded the treated areas [117].

4.6.2/ Control of Noxious Weeds

Wild Carrot

In a 3 year study in Alabama, timing of mowing, frequency of mowing and herbicide treatments for wild carrot control were examined along roadsides [118]. The best control was obtained over the years with an early June mowing following three weeks later by a treatment of MSMA (monosodium salt of methylarsonic acid), diuron and a surfactant, an early August mowing followed three weeks later by

the same herbicide treatment and a dormant application of sulfomethuron methyl. The dormant herbicide treatment was designed to remove winter annuals.

Thistles

Combinations of cultivation, mowing and competitive crops used with herbicides are more effective than herbicides alone in the control of Canada thistle [42]. Alfalfa, with mowing twice each year, reduced the count of Canada thistle to 14% of the original figure after one year and to zero after four years [119].

Perennial weeds such as Canada thistle are best controlled using a variety of strategies [120]. These weeds should be mowed once or twice in early and midsummer to weaken the plants by reducing their underground root reserves. Next, a late summer treatment of a systemic herbicide should be applied to the foliage to further weaken the plants so that few will survive the winter. The following season, the area can be fertilized to stimulate grass growth and competition. Mowing the area again will further reduce the number of surviving Canada thistle plants and active growth of the grass.

Combinations of herbicides (3,6-dichloropicolinic acid and 2,4-D; picloram and 2,4-D; dicamba and 2,4-D) and nitrogen fertilizer were applied to several plots of Canada thistle and nodding thistle in Nebraska during the spring over a three year period [121]. All treatments provided excellent control and annual treatments controlled the few plants that emerged after the first application. It was found, however, that the application of nitrogen may have given the thistles a competitive advantage over perennial grasses.

4.7/ Reducing Weed Problems Following Construction

4.7.1/ Early Establishment of Competitive Vegetation

Developing vegetation cover on construction sites as soon as possible reduces weed invasion and minimizes long-term weed control problems. The Virginia Department of Transportation employs stage seeding on its contracts [122]. Contractors are required to seed within 48 hours of reaching a grading increment; increments of five feet must be seeded. Slopes higher than 15 feet require three increments. Slopes greater than 2:1 must be grooved horizontally or benched while slopes less than 2:1 must be roughed before seed is applied. Both roughing and grooving slopes provide a good seed bed by allowing seed a place to catch during rains and also slows the velocity of water as it runs down the slopes. Straw mulch is also applied and is tacked in place by wood cellulose fiber.

North Carolina has had good success in revegetating chronically eroding slopes along roadsides using hardwood bark [123]. The area was hydroseeded with no grading or seedbed preparation and a layer of hardwood bark was applied as a mulch using an Ester bark spreader/blower.

In Pennsylvania the district roadside unit is involved in all facets of design, construction, and maintenance that relate to the roadside and its environment [124]. In this capacity, roadside slopes and soil areas can be designed, graded, rounded, finished, and vegetatively treated to yield the best finished product with long-term maintenance in mind.

Hydromulching, the method of applying seed, fertilizer, soil stabilizer and seed cover in a one-step operation, is an effective method of grass and legume establishment on slopes. Four main components of a good hydromulching system are: seed selection, mulch selection, fertilizer selection and soil stabilizer selection [125]. Grass cultivar selection was discussed in Section 4.2.1.3.

The purpose of the mulch in the hydromulching system is to provide a cover to protect the seed and help keep it moist, to protect the soil surface from the impact of the raindrops until vegetation covers the ground, and to provide a ground cover that will help link soil particles together and prevent them from being dislodged by wind and rain [125]. Commonly used mulching materials include paper, wood fibre and straw. Hay, excelsior mat and wood chips gave the best results in a Massachusetts study [37].

During the critical period prior to germination, stabilizers help bind the mulch, seed and soil particles together without forming a crust that will prevent water and air penetration. The two general groups of stabilizers are the tackifiers and soil stabilizers. Tackifiers, which are the least expensive and most temporary stabilizers, adhere the mulch and seed to the soil surface and, generally, do not bind the soil particles together except at the surface. Soil stabilizers are composed of organic chemical compounds which stabilize the soil particles by penetrating the soil and altering the physical structure. Although these are the most expensive products, they provide benefits on very steep slopes.

DCA-70 (Union Carbide) mixed with water showed excellent sand-binding power and very good erosion control with no adverse effects on germination and seedling establishment of grasses [37].

When feasible, fertilization should be based on soil analysis of samples taken from the areas to be seeded [125]. The fertilizer assists in early root development and plant growth. Nitrogen is less critical than potassium and phosphorus. The selected fertilizer should provide long term nourishment to the plant and so, ideally, it should be a slow release fertilizer [125].

Research performed in Maine showed that the phosphorus fertilization needs could be satisfied largely or wholly at the initial seeding, and there was little need for top-dressed phosphorus for several years after seeding [126]. Depending on soil analysis, Stafford indicated that fertilization rates at the time of hydroseeding should be between 112 to 224 kg P_2O_5/ha but that all hydroseeding should receive at least 112 kg P_2O_5/ha to ensure rapid seedling growth.

The potassium fertilization needs for sod maintenance are less readily satisfied by a single application of fertilizer at the initial seeding [126]. During prolonged dry weather, salt injury may result to germinating seeds wher. fertilizer rates in excess of 112 to 168 kg K_2O/ha are applied. Soils that test very low in available potassium may require a supplemental dressing of potassium within a year or two following initial seeding especially if legumes are present in the seed mixture. Rates up to 224 kg K_2O/ha may be top-dressed without any concern for injury to the established grass of legume-grass sod.

At initial seeding, nitrogen should not be applied in excess of 100 kg N/ha because significant losses of nitrogen through leaching and denitrification may result in seedling injury (especially in dry weather) and reduced seedling populations may occur [126]. Excessive nitrogen may also suppress the establishment of associated legumes through unusually rapid growth of the competing grasses.

Generally, grass sods on slopes having no topsoil should receive top-dressed nitrogen within 2-4 months after the initial hydroseeding. Spring and early summer seedings should be top-dressed until the following spring. The rate of fertilization should rarely exceed 100 kg N/ha. A second top-dressing is often necessary within 3-6 months after the first. While nitrogen top-dressing may be terminated 1-2 years after the initial hydroseeding, at some point, however, grass grown on subsoils with little organic matter will need additional applications of nitrogen [126].

Seeds pressed into the soil by corrugated rollers or drill seeders with compaction wheels have better access to soil moisture than seeds deposited on a loose soil surface [127]. While rollers and drills cannot operate on slopes steeper than 3.5 to 1, they generally produce better stands where they can be used. Drill seeding is particularly advantageous under stressful conditions [127].

Maine has also developed two successful, low-cost legume establishment techniques: 1) direct overseeding on established grassland; and 2) one-year containerized transplants [128]. In directly overseeding crown vetch and birdsfoot trefoil the grassed area must either be scarified or herbicide must be applied. Best ground cover was achieved with a May seeding on grass that had been treated with paraquat [126]. Virtually 100% survival was obtained using containerized transplants of crown vetch. The desired spacing of crown vetch transplants varied with soil conditions, slope exposure and other factors. It appeared that supplemental fertilization was highly important to vigorous rhizome growth. Potassium was the key nutrient element in this regard, and it was recommended that transplants be top-dressed with a high-potash fertilizer (e.g. 0-10-40) sometime during the second year following planting [126].

In Massachusetts, application of 0-20-20 fertilizer and remedying limestone deficiencies in soils prior to seeding crown vetch gave good establishment and growth [37]. Attempts to establish this species in

combination with grass species were generally not successful because the crown vetch was choked out by the rapid growth of the faster-growing grass. Nurse crops seeded with crown vetch were very beneficial in controlling erosion on newly constructed slopes but to prevent competition with crown vetch it is important that the nurse crop be seeded at a rate of no more than 20 lb/acre. Other legumes were successfully spot seeded on 5 foot centres onto slopes and flat areas covered with wood chips as mulch.

4.7.2/ Construction Treatments to Minimize Early Breakdown of Structures

North Carolina Department of Transportation personnel apply soil residual herbicides under asphalt islands before they are capped. Joints in concrete islands are cleaned out and filled with a mixture of liquid asphalt and a residual herbicide [129].

4.7.3/ Survival of Amenity Plantings

Recent studies have evaluated the Ministry's specifications for tree planting and maintenance [130]. Therefore, methods to control undesirable vegetation growth in amenity plantings will only be discussed briefly.

Studies have indicated that broad-leaved herbaceous plants and grass growing around the base of young trees drastically reduces their growth and nutrient status. The responses of broadleaved and coniferous tree species are very similar. Potter and Colderick found that it was not possible to overcome the detrimental effect of grass competition by irrigation and/or nitrogen application [131]. They concluded that it is essential for young trees to be free from competition for water and nutrients in order to recover from planting shock and to grow vigorously. Two practical methods of controlling weeds in amenity plantings are mulches and herbicides.

Recent reviews outline the numerous benefits of mulches which include suppression of weed growth, conservation of soil moisture and prevention of soil erosion [132,133]. Additional benefits such as elevation of soil temperature in winter and cooling of soil in summer, improvement of soil aeration and structure, reduction of soil bulk density and addition of nutrients are dependent on the type of mulch and other factors [132]. Consequently, reports in the literature can be contradictory. It is claimed that mulch can immobilize soil nitrogen, promote plant diseases and encourage rodent infestations. Mulches are used in so many different situations and can affect so many different interacting soil factors that it is not usually possible to identify only one factor as being the main reason for good or bad results [133]. In most amenity plantings, however, application of mulch does yield some benefit.

In recent studies along Ontario roadsides, herbicide treatments compared favourably with the use of organic mulches [130]. The main advantage of using herbicides over mulching was the lower cost of herbicide application.

In applying mulch, individual soil types and their physical characteristics should be considered [132]. Sandy soils can be mulched deeper than heavy or wet soils. Light, or coarse, textured materials can be applied in thicker layers than fine-textured mulches such as peat or sawdust. Generally, mulches such as bark can be applied 75 to 100 mm deep around woody plants [132,133].

Present Ministry specifications of 100 mm bark mulch were found to promote the growth of young ash trees in clay soils [129].

5/ Development of Weed Control Programs Using the IWM Approach

Broadly defined, integrated weed management (IWM) encompasses a multitude of components ranging from technical considerations to public relations and administrative issues. A basic definition of IWM is the use of two or more strategies to achieve weed control goals. The focus of a multifaceted approach for highway agencies is to reduce reliance on controversial techniques, such as herbicide use, and to lower maintenance costs in the long-term.

The literature reveals a wide variation in the application of IWM approaches by roadside vegetation management agencies. Most agencies commonly use a two-level IWM program where chemical weed control supplements the practice of mechanical mowing. Certain U.S. state agencies add staff training as a third component to this simple, two-level program, while others add public relations. Some agencies in Colorado and California, for example, have incorporated several components into elaborate IWM programs as a result of increased public pressure to reduce pesticide use [74,134].

A comprehensive IWM program ensures that specific vegetation management techniques are used in the appropriate spatial and temporal context in order to maximize the effectiveness of the IWM approach. Inherent to an effective IWM program is the need for individual, interrelated components to be considered within a common framework, during the research, evaluation and operation stages. Few roadside vegetation management agencies identified in the literature possess an IWM program that reflected inter-connection between components. Rather, individual components seem to be developed and operated independently of other components. Furthermore, once a particular technique is adopted it is often resistant to change despite the need for it to be constantly refined, not only in view of its own performance, but also in relation to the performance of other techniques. The IWM program should demonstrate flexibility as it adapts to various external pressures caused by budget restrictions, public pressure or staff capabilities.

In conjunction with other facets of the IWM program, it is essential to undertake inventories of various features relating to vegetation management along roadsides. These features should be mapped and could include noxious weed problems by species, brush control problems, localized public concerns regarding roadside management, and natural regeneration areas. It is necessary to have comprehensive information on the problems and problem species involved before prescribing suitable control measures. The context in which the problem is occurring may also be of relevance. For instance, is the noxious weed problem adjacent to forested, agricultural, residential or industrial land uses? What vegetation species are presently growing with the problem species? Is the problem real or perceived? Can public education help to resolve the perception of the problem? Adequate inventories also provide a realistic appreciation of the scope of the various problems and how funds can be best allocated.

These inventories could be collected and utilized at either central or district levels. They could be incorporated within a geographical information system (GIS) framework. Such a system could interface with additional inventory information located within a database. The GIS could provide a powerful management tool for the IWM programs, since several layers of geographical information can be analyzed at once.

Adequate monitoring of individual vegetation management techniques is essential in order to evaluate how each technique is functioning within the context of the overall IWM program. Monitoring is also important in natural regeneration areas to determine which species are developing over time and if other techniques, such as selective chemical removal of certain undesirable species, are needed to encourage those species having more desirable characteristics. In certain situations, baseline studies may be required to determine what conditions existed prior to applying specific IWM techniques. Monitoring serves as a tool to aid the vegetation manager in constantly tailoring the IWM program to make it more efficient.

Chapter 4 identifies numerous vegetation control techniques which could potentially become part of IWM programs for Ontario roadsides. Possible ways in which these individual techniques can be integrated into IWM programs are illustrated using two examples: one for brush control and the other for turf weed control.

5.1/ Integrated Program for Brush Control

The literature suggests that trees can be effectively excluded from certain shrub and herbaceous plant communities possibly due to the combined effects of allelopathy, competition and tree seedling death due to rodents. An IWM program aimed at brush control could have as a goal the establishment and

maintenance of such tree-excluding communities. This program would integrate several components such as chemical, mechanical and biological control.

Chemical control - One or more basal application techniques can be used to control trees as they reach unacceptable heights. These application techniques allow only the trees to be targeted leaving desirable shrubs and herbaceous plants to pursue their growth. Once it is dense enough, the shrub and herb community would itself suppress invasion to a great extent. The cut and surface treatment technique can also be used to achieve similar results.

Mechanical control - In areas where it is less desirable to use herbicides, trees can be removed mechanically by cutting or by using a hand-held torch to girdle the stems.

Biological control - A dense, low-growing shrub or herbaceous plant community would reduce tree seedlings through competition, allelopathy or by providing habitat for numerous rodents.

5.2/ Integrated Program for Turf Weed Control

One objective of a turf weed control program using the IWM approach could be to establish and maintain weed-excluding communities of vegetation along the sideslope and backslope of roads and highways in southern Ontario. Once established, such a community might only require periodic maintenance to renew sites in decline or to control localized weed problems.

In existing turf areas the objectives of a weed control program using the IWM approach would be to improve the competitiveness of the turf cover and to control localized weed infestations on a spot basis. A turf weed control program would comprise several components such as mechanical, chemical, cultural and biological control as well as inventories and monitoring as previously mentioned.

Mechanical control - Mowing of the safety clear zone remains a standard feature of vegetation management along roadsides and many noxious weeds are suppressed in this manner within this zone. Repeat mowing can be used to control certain weeds on any portion of the right-of-way. Wild carrot, for instance, has been controlled by a single mowing in late summer while Canada thistle was controlled by mowing once or twice in early summer, applying a systemic herbicide in late summer, fertilizing the following season to stimulate grasses and mowing in summer. One of the mowing cycles in thistle control should take place within two days of opening of the first terminal flowers to prevent seed production. As previously outlined, mowing can be successfully combined with cultural and chemical techniques to give effective thistle control.

Chemical control - Herbicides can be spot sprayed or wiper applied to control particularly troublesome areas of weed growth.

Cultural control - Once a particular infestation on an established site has been treated by mowing or herbicide application, desirable plants should be encouraged by fertilizing and/or overseeding the area.

Biological control - A dense, low-growing shrub or herbaceous plant community would reduce noxious weed growth through competition or allelopathy. Such communities could be encouraged or expanded where they already exist and planted in other appropriate sites.

5.3/ Research Required for Integrated Programs

Crucial to any weed control program is the need for ongoing research to improve the effectiveness of individual components of the program. Techniques identified in the literature vary greatly with respect to their need for additional research. These techniques can be divided into three categories based on their need for additional research prior to use in Ontario: existing technology, short-term research and long-term research.

Existing Technology

Techniques such as stage seeding on construction sites and mowing within two days of flowering for Canada thistle control in established turf can be incorporated immediately into vegetation management strategies for Ontario roadsides. Preplanting control of perennial weeds should be practiced wherever possible before planting shrub beds, ground covers and before seeding. Mulch can also be used to reduce weed growth in amenity plantings.

Short-term research

Several weed control techniques have proven successful elsewhere but require additional research before being widely used in Ontario. These include:

- dormant and repeated cutting for cattail control in ditches;
- combined mowing, herbicide application and fertilization for control of Canada thistle;
- establishment of grasses and other herbaceous and woody species to compete with noxious weeds;
- the use of low-growing vegetation communities that exclude tree species;
- low-volume basal techniques to apply herbicides;
- hand-held torches to girdle unwanted saplings;

- hand cutter with herbicide injection;
- cut surface treatment and cut stubble treatments.

Long-term research

Certain options for roadside weed control require long-term research before they become widely used in Ontario. This includes the use of insects and pathogens as biological control agents in the control of certain weeds. While promising, biological control requires substantial research for it to become practical on roadsides. This includes the ongoing testing of new organisms for the control of noxious weeds. Although the Ministry could test the effectiveness of a selected organism in a roadside context, it is beyond the Ministry's scope to undertake basic biological control research. The Ministry should, however, keep abreast with research in the area of biological control and should test any organism which has proven effective in agricultural situations.

Research into the allelopathic relationships between plants is also an area which shows promise but which requires long-term study to become widely applicable. For now, however, species which exhibit proven allelopathic effects on noxious weeds should be encouraged to flourish along roads and highways.

Additional areas requiring long-term research include heat irradiation techniques, herbicide research and herbicide application technology.

6/ Proposed Areas of Research

6.1/ Introduction

This section briefly outlines specific research projects which could be undertaken by the Ministry in order to further their involvement in integrated vegetation management.

6.2/ Research Project 1 - Establishment of Low-Growing Vegetation Communities

6.2.1/ Objectives

- To determine the feasibility of establishing low-growing vegetation communities along Ontario roadsides;
- to determine which species have potential for developing into low-growing, tree-excluding communities;

- to determine which species would need to be selectively removed in order to promote the establishment of a low-growing community; and
- to determine the length of maintenance intervals.

6.2.2/ Scope

At present, there is a lack of information on natural regeneration dynamics along Ontario roadsides. Prior to developing management strategies which would utilize competitive vegetation to suppress tall growing vegetation, it is necessary to know the species which regenerate once chemical or mechanical control ceases.

The Ministry has performed research on natural regeneration techniques for Ontario roadsides during the late 1970's and early 1980's [135,136]. Results indicated that certain species found along Ontario roadsides had potential for use as low-growing, tree-resistant communities (for example, species listed in Table 4).

As an initial phase, the 60 plots used in the Andresen studies [135,136] should be reassessed to determine their present vegetation composition. Although the Andresen studies incorporated trees and tall-growing shrubs into their desirable species list, the results yield valuable information regarding vegetation dynamics along roadsides. Also, these studies provide information on adjacent vegetation, thereby lending insight on the influence of offsite features on community composition along the roadside. In managing for low-growing vegetation, it is useful not only to have information on vegetation having desirable characteristics but also on those species which would need to be selectively removed.

Subsequent research could focus on selectively removing vegetation with undesirable characteristics and observing the effects of this disturbance on the resulting vegetation dynamics. New plots may need to be established to determine the effects of earlier removal of undesirable vegetation on subsequent community development. All broadcast chemical spraying and mowing activity would need to cease within these areas. There is also a need for information on the length of time that a community remains "treeless" before selective removal must once again be done.

Table 4 presents a list of species that have shown the potential to exclude tree invasions and should be consulted in developing a list of desirable, low-growing plants for roadside use.

6.2.3/ IWM Context

Research on natural regeneration of low-growing vegetation could be combined with research on selective vegetation removal techniques such as basal bark application techniques. Efficient, low-cost selective vegetation removal is a required component of the overall competitive vegetation strategy.

To ensure the social acceptability of natural regeneration along the roadside, a public relations and education program would need to be established. People travelling the highways and roads need to appreciate the reasons for natural regeneration as a viable roadside vegetation management strategy. The use of signs, as is now used to identify natural regeneration areas for MTO roadside personnel, would be a valuable tool in educating the public. In general, the natural regeneration areas must be perceived as having a purpose, otherwise they will be viewed as neglected and complaints may increase.

6.3/ Research Project 2 - Establishment of Competitive Grasses and Forbs

6.3.1/ Objectives

- To determine which mixture of grass and forb species and cultivars yield best results for the various growing conditions in Ontario; and
- to determine the most appropriate establishment and maintenance techniques for turf cover.

6.3.2/ Scope

Maintaining healthy turf will remain a viable strategy for precluding noxious weeds and for erosion control in urban and other areas along Ontario roadsides. Establishing appropriate grass and forb species and cultivars is a basic requirement for a healthy, low-maintenance turf. The Ministry should consider undertaking research aimed at determining effective seed mixtures for the various Ontario conditions. Some of these cultivars may include those mentioned in Section 4.2.1.3.

Fertilizer and lime trials could also be undertaken in order to determine best ratios for the various growing conditions. These techniques may be utilized in the more intensely managed urban situations.

6.3.3/ IWM Context

The establishment of competitive grass and forb communities along certain sections of roadsides would reduce the need for chemical spraying since the healthy turf would inherently inhibit noxious weed invasions. Herbicide applications should be on the basis of need and should involve selective or low volume applications where suitable.

6.4/ Research Project 3 - Comparative Study of Low-Volume Chemical and Non-Chemical Selective Vegetation Control Along Ontario Roadsides

6.4.1/ Objectives

- Compare various low-volume basal herbicide application techniques (see Table 5) in terms of efficacy and cost-effectiveness;
- evaluate efficacy of hand-held torches (Section 4.3.1) and herbicide-injecting cutters; and
- evaluate efficacy and cost-effectiveness of wiping applicators for selective control of tall herbaceous and woody vegetation (Section 4.5.1).

6.4.2/ Scope

Using techniques which provide vegetation control equivalent to that provided by conventional methods but which require less herbicide is desirable. Studies indicate the benefits of low-volume basal techniques but these should be assessed in Ontario conditions along with hand-held torches and herbicide-injecting cutters. Carriers other than fuel for low-volume basal techniques should be evaluated as well. Research has shown that mineral oil may be an adequate substitute and has more desirable characteristics.

6.4.3/ IWM Context

Inherent to the principles of IWM is the need to decrease dependence on or use of chemicals for vegetation control. Selective vegetation control is a necessary initial feature in the establishment of native, low-growing vegetation communities and so any use of selective control techniques will be beneficial to the overall IWM program. A public education program stressing the low-volume, selective approach to herbicide application may encourage public understanding of these types of chemical application on roadsides.

6.5/ Research Project 4 - Control of Undesirable Vegetation in Amenity Plantings

6.5.1/ Objectives

- Evaluate various mulch materials for grass and forb control around roadside amenity plantings; and
- evaluate pre-emergent herbicides, either alone or in combination with mulch, in reducing undesirable vegetation in amenity plantings.

6.5.2/ Scope

Research has shown that mulch has additional benefits to reducing weed growth in amenity plantings. The probability of survival of the landscape plants themselves is increased either by increasing available soil moisture, reducing competition with weeds and reducing rodent damage. There is a need for research to determine the additional benefits of using pre-emergence herbicides in relation to costs. A mulch evaluation program could also be initiated to determine the availability, feasibility and cost of alternative mulches compared to the usual wood chips. These could include, among others, by-products from food processing industries.

6.5.3/ IWM Context

The integrated use of multiple techniques to increase the survival of landscape plant materials could provide substantial cost savings. This could be combined with trials to evaluate various plant materials for use along roadsides.

6.6/ Research Project 5 - Integrated Control of Thistles

6.6.1/ Objective

- To determine the feasibility of using multiple techniques to control Canada thistle and nodding thistle.

6.6.2/ Scope

The combined approach of herbicide treatment, mowing and improving turf competitiveness to control thistles should be studied under Ontario conditions. Timing of herbicide and mowing treatments are important considerations. The length of the interval between treatments should also be determined. This strategy could also be tried with other noxious weeds.

6.6.3/ IWM Context

Using multiple techniques to control thistle species fits within the framework of any overall IWM program for roadside vegetation management. It could also be combined with evaluations of biological agents to control thistles.

6.7/ Research Project 6 - Biological Control of Thistles

6.7.1/ Objective

- Evaluate the effectiveness of *Rhinocyllus conicus* and *Trichosirocalus horridus* as thistle control agents along roadsides.

6.7.2/ Scope

Previous releases of *Rhinocyllus conicus* and *Trichosirocalus horridus* have proven successful for control of thistle species and these two organisms likely occur already along roadsides in certain areas of Ontario. These two agents could be introduced and evaluated in new areas and, in areas where they already occur, populations could be artificially augmented by releasing additional organisms and the impacts on thistle stands could be studied.

6.7.3/ IWM Context

Biological control of thistles could be studied in conjunction with mechanical and chemical control (see Section 6.6) to determine the effects of one technique on the other in terms of effectiveness. Signage could be erected to identify biocontrol research areas. The novel nature of biocontrol as a weed control strategy for roadsides would likely create much public interest and support.

7/ References

[1] Ontario Ministry of Transportation. 1989. *Pesticide Spray Manual.*

[2] Ministry of Transportation and Communications. 1981. Maintenance Quality Standards. M-300-1, Grass Control. M-300-2, Weed Control. M-300-3, Brush Control. M-300-4, Maintenance of Roadside Plantings. M-300-5, Natural Regeneration.

[3] Dance, K.A. 1990. *Review of Existing Vegetation Management Practices and Identification of Future Research Needs.* Ontario Ministry of Transportation, Research and Development Branch, RR-243, 41 pp.

[4] National Research Council. 1989. *Alternative Agriculture.* National Academy Press, Washington, D.C. .

[5] Bovey, R.W. 1987. Weed control problems, approaches and opportunities in rangeland. *Reviews of Weed Science* 3:57-91.

[6] Connell, J.H. and R.O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist* 111:1119-1144.

[7] McIntosh, R.P. 1980. The relationship between succession and recovery process in ecosystems. In *The Recovery Process in Damaged Ecosystems.* Cairns, J., editor. Pages 11-62.

[8] Miles, J. 1987. Vegetation succession: past and present perceptions. *In Colonization, Succession and Stability.* Gray, A.J., M.J. Crawley and P.J. Edwards, editors. Blackwell Scientific Publications, Oxford. Pages 1-29.

[9] Niering, W.A. and R.H. Goodwin. 1974. Creation of relatively stable shrublands with herbicides: arresting "succession" on rights-of-way and pastureland. *Ecology* 55:784-795.

[10] Pound, C.E. and F.E. Egler. 1953. Brush control in southeastern New York: fifteen years of stable tree-less communities. *Ecology* 34:63-73.

[11] Egler, F.E. and S.R. Foote. 1975. *Plight of the Right-of-way Domain: Victim of Vandalism.* Future Media Services, Mt. Kisko, New York.

[12] Bramble, W.C. and W.R. Byrnes. 1972. A long-term ecological study of game food and cover on a sprayed utility right-of-way. *Purdue Univ. Agric. Exp. Stn. Res. Bull.* 855:1-20.

[13] Niering, W.A. and F.E. Egler. 1955. A shrub community of *Viburnum lentago,* stable for twenty-five years. *Ecology* 36:356-360.

[14] Rusch, A.J., D.R. Thompson and C. Kabat. 1980. Management of roadside vegetation cover by selective control of undesirable vegetation. *Wisconsin Department of Natural Resources.* Tech. Bull. No. 117.

[15] Egler, F.E. 1954. Vegetation management for rights-of-way and roadsides. *Annual Report of the Board of Regents of the Smithsonian Institution.* 1953. Publication 4149:299-322.

[16] Suffling, R.C. 1975. *Selected Ecological Factors Influencing Brush Control Using Tordon 101 Herbicide.* Doctoral thesis. Dept. of Botany and Genetics. Univ. of Guelph.

[17] Putnam, A.R. 1985. Allelopathy: a viable strategy for weed control? *1985 British Crop Protection Conference - Weeds.* Pages 583-589.

[18] Foster Jr., R.E. 1984. Allelopathy and its potential applications in right-of-way management. *Transportation Research Record* 969:27-31.

[19] Patterson, D.T. 1986. Allelopathy. In *Research Methods in Weed Science.* Third Edition. N.D. Camper, editor. Southern Weed Science Society. Pages 111-134.

[20] Touchette, R., G.D. Leroux and J.M. Deschenes. 1988. Allelopathic activity of quackgrass *(Agropyron repens)* extracts and residues on alfalfa (*Medicago sativa*). *Can. J. Plant Sci.* 68:785-792.

[21] Horsley, S.B. 1977. Allelopathic inhibition of black cherry by fern, grass, goldenrod, and aster. *Can. J. For. Res.* 7:205-216.

[22] Horsley, S.B. 1977. Allelopathic inhibition of black cherry. II. Inhibition by woodland grass ferns, and club moss. *Can. J. For. Res.* 7:515-519.

[23] Einhellig, F.A. and G.R. Leather. 1988. Potentials for exploiting allelopathy to enhance crop production. *J. of Chemical Ecology* 14:1829-1844.

[24] Einhellig, F.A. and J.A. Rasmussen. 1989. Prior cropping with grain sorghum inhibits weeds. *J. of Chemical Ecology* 15:951-960.

[25] Harper, B. 1988. Return of the natives to Minnesota roadsides. *Transportation Research Record*. 1189:78-80.

[26] Harper-Lore, B. 1990. Now that we have your attention! *Public Works*. 121(4):47-49.

[27] Heine, M. 1990. Prairie motif saves on maintenance, costs. *Roads & Bridges* 28(2):34-35.

[28] Nelson, K. 1990. Missouri improves its roadside maintenance program. *Public Works*. 122(3):52-53.

[29] Ritzer, J. 1990. The what and why of natural roadsides. *Public Works*. 121(3):49-52.

[30] Duell, R.W. 1989. Minimize maintenance: select right grasses. *Roads & Bridges*. 27(9):77-79,84.

[31] Dusablon, C.A. 1988. Renewed interest spurs wildflower research in Vermont. *Public Works*. 119(3):56-59.

[32] Elmhirst, J.F. and N.P. Cain. 1990. *Review of Roadside Wildflower Programs and Assessment of Feasibility in Ontario*. Ontario Ministry of Transportation, Research and Development Branch, MAT-90-05.

[33] Stainton, L. 1987. Using native vegetation for roadside plantings. *Public Works*. 118(3):59-60.

[34] Rinard, J.E. 1986. Roadside vegetation management in Idaho. *Transportation Research Record*. 1075:11-14.

[35] Baker, R.F. 1983. Roadside vegetation: implementation of fine fescue grasses. *Transportation Research Record*. 913:23-28.

[36] Duell, R.W. 1989. Vegetation enhancement via species and cultivar selection: a perspective. *Transportation Research Record*. 1246:49-53.

[37] Zak, J.M. 1983. Vegetation of roadside slopes in Massachusetts. *Transportation Research Record*. 913:11-14.

[38] Darveau, M. and P. Bellefleur. 1984. Dynamique de la vegetation d'emprises de lignes de transport d'energie. *Can. J. Bot.* 62:1730-1738.

[39] DOTS improve vegetation management practices. *Better Roads*. 1987, 57(2):40-44.

[40] Timmons, F.L. 1946. Studies on the distribution and floss yield of common milkweed (*Asclepias syriaca* L.) in Northern Michigan. *Ecology* 27:212-225.

[41] Goodwin, M. 1981. *Cost and Effectiveness of Alternatives to Picloram for Canada Thistle Control on Smithers Roadsides*. British Columbia Ministry of Transportation and Highways.

[42] Moore, R.J. 1975. The biology of Canadian weeds. 13. *Cirsium arvense* (l.) Scope. *Can. J. Plant Sci.* 55:1033-1048.

[43] Desrochers, A.M., J.F. Bain and S.I. Warwick. 1988. The biology of Canadian weeds. 1989. *Carduus nutans* L. and *Carduus acanthoides* L. *Can. J. Plant Sci.* 68:1053-1068.

[44] McCarty, M.K. and C.J. Scifres. 1969. Life cycle studies with musk thistle. *Nebraska Agric. Exp. Sta. Rep. Bull* 230.

[45] Johnson, W.D. 1988. The use of herbicides in roadside maintenance. *Transportation Research Circular* 342.

[46] Hay, H. 1988. Oregon balances ecology, vegetation control methods. *Roads & Bridges*. 26(2):47-48.

[47] Grader/brush cutter aids roadside maintenance. *Public Works* . 1986, 117(3):78-79.

[48] Olson, D.P., S. Macrigeanis and W.J. Davis. 1981. Use of hand-held torches in managing woody vegetation on rights-of-way. In *Environmental Concerns in Rights-of-way Management*. Proceedings of Second Symposium, Oct. 16-18, 1979. Electric Power Research Institute EPRI WS-78-141. Pages 28-10.

[49] Anon. 1990. Roadside planting that reduces costs. *Better Roads*. 60(5):33-35.

[50] Jett, C. 1988. Missouri's new vegetation management program. *Public Works*. 119(10):99-101.

[51] Roybal, B. and G. Stem. 1987. Centralization improves roadside maintenance program. *Public Works* 118(3):56-588.

[52] Parish, S. 1989. Weed control - testing the effects of infrared radiation. *The Agricultural Engineer* 44(2):53-55.

[53] Johnson. D.W., J.M. Krall, R.H. Delaney and D.S. Thiel. 1990. Response of seed of 10 weed species to Fresnel-lens-concentrated solar radiation. *Weed Tech.* 4:109-114.

[54] Sale, P.J.M. and R.G. Wetzel. 1983. Growth and metabolism of *Typha* species in relation to cutting treatments. *Aquatic Bot.* 15:321-334.

[55] Jordan, T.E. and D.F. Whigham. 1988. The importance of standing dead shoots of the narrow leaved cattail, *Typha angustifolia L. Aquatic Bot.* 29:319-328.

[56] Garver, E.G., D.R. Dubbe and D.C. Pratt. 1988. Seasonal patterns in accumulation and partitioning of biomass and macronutrients in *Typha* spp. *Aquatic Bot.* 32:115-127.

[57] Dale, H.M. 1974. The biology of Canadian weeds. 5. *Daucus carota. Can J. Plant Sci.* 54:673-685.

[58] Harrison, P.J. and H.M. Dale. 1966. The effects of grazing and clipping on the control of wild carrot. *Weeds* 14:285-288.

[59] Bassett, I.J. and C.W. Crompton. 1975. The biology of Canadian weeds. II. *Ambrosia artemesiifolia* L. and A. *psilostachya* DC. *Can. J. Plant Sci.* 55:463-476.

[60] McCarty, M.K. and J.L. Hatting. 1975. Effects of herbicides or mowing on musk thistle seed production. *Weed Research* 15(6):363-367.

[61] Watson, A.K. 1989. Current advances in bioherbicide research. *Brighton Crop Protection Conference, Weeds, 1989.* Vol. 3:987-996.

[62] Schroeder, D. 1983. Biological control of weeds. In *Recent Advances in Weed Research*. W.W. Fletcher, editors. Slough: Commonwealth Agricultural Bureaux. pp. 41-78.

[63] Grace, J.B. and J.S. Harrison. 1986. The biology of Canadian weeds. 73. *Typha latifolia L.,Typha angustifolia L. and Typha zglauca* Godr. *Can. J. Plant Sci.* 66:361-379.

[64] Bhowmik, P.C. and J.D. Bandeen. 1976. The biology of Canadian weeds. 19. *Asclepias syriaca* L. *Can. J. Plant Sci.* 56:579-589.

[65] Beattie, A.J., C. Turnbull, T. Hough, S. Jobson, and R.B. Knox. 1985. The vulnerability of pollen and fungal spores to ant secretions: evidence and some evolutionary implications. *Am. J. Bot.* 72:606-614.

[66] Kevan, P.G., D. Eisikowitch and B. Rathwell. 1989. The role of nectar in the germination of pollen in *Asclepias syriaca* L. *Bot. Gaz.* 150(3):266-270.

[67] Kevan, P.G., D.L. Collins-Thompson and D. Eisikowitch. 1989. Milkweeds, pollinators and yeasts: a system for potential biocontrol of milkweed seed production. *Highlights* 12(3):21-24.

[68] Bassett, J. I. and C.W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. *Can. J. Plant Sci.* 62:1003-1010.

[69] Lemna, W.K. and C.G. Messersmith. 1990. The biology of Canadian weeds. 94. *Sonchus arvensis L. Can. J. Plant Sci.* 70:509-532.

[70] Peschken, D.P. and J.L. Derby. 1988. Host specificity of *Liriomyza sonchi* Hendel (*Diptera: Agromyzidae)*, a potential biological agent for the control of weedy sow-thistles, *Sonchus* spp. in Canada. *Can. Entomoligist.* 120:593-600.

[71] Julien, M.H. (editor). 1987. *Biological Control of Weeds: a world catalogue of agents and their target weeds.* Second edition. Commonwealth Agricultural Bureaux International Institute of Biological Control.

[72] Peschken, D.P. 1984. *Cirsium arvense* (L). Scope., Canada thistle (compositae). In *Biological Control Programmes against Insects and Weeds in Canada 1969-1980.* J.S. Kelleher and M.A. Hulme, editors. Commonwealth Agricultural Bureaux, U.K. pp. 139-146.

[73] Peschken, D.P., D.B. Finnamore and A.K. Watson. 1982. Biocontrol of the weed Canada thistle (*Cirsium arvense)*: releases and development of the gall fly *Urophora carduii* (Diptera: tephritidae) in Canada. *Can. Entomologist* 114:349-357.

[74] Fuller, M. 1990. Weed control blossoms into revegetation program. *Roads & Bridges.* 28(2):36-37.

[75] Turner, C.E., R.W. Pemberton and S.S. Rosenthal. 1987. Host utilization of native *Cirsium* thistles (Asteraceae) by the introduced weevil *Rhinocyllus conicus* (Coleoptera: Curcu lionidae) in California. *Environ. Entomol.* 16:111-115.

[76] Harris, P. 1984. *Carduus nutans* L., nodding thistle and *C. acanthoides* L., plumeless thistle (compositae). In *Biological Control Programmes Against Insects and Weeds in Canada 1969-1980.* J.S. Kelleher and M.A. Hulme, editors. Commonwealth Agricultural Bureaux, U.K. Pages 115-126.

[77] Miller, R.V., E.J. Ford, N.J. Zidack and D.C. Sands. 1989. A pyrimidine auxotroph of *Sclerotinia sclerotiorum* for use in biological weed control. *J. of Gen. Microbiology* 125:2085-2091.

[78] Kok, L.T. 1986. Impact of *Trichosirocalus horridus* (Coleoptera: Curculionidae) on *Carduus* thistles in pastures. *Crop Protec.* 5:214-217.

[79] Batra, S.W.T. 1981. Biological control of *Carduus* thistle along roadsides in northeastern states. *Transportation Research Record.* 805:1-2.

[80] Politis, D.J. and Brockart, W.L. 1986. Infection of the musk thistle *(Carduus nutans)* by *Puccinia carduorum* influenced by conditions of dew and plant age. *Plant Dis.* 70:288-290.

[81] Mathews, G.A. and R.P. Garnett. 1983. Herbicide Application. In *Recent Advances in Weed Research.* Fletcher, W.W., editor. Commonwealth Agricultural Bureaux, England. Pages 33-40.

[82] McWhorter, C.G., F.E. Fulgham and W.L. Barrentine. 1988. An air-assist spray nozzle for applying herbicides in ultralow volume. *Weed Science* 36:118-121.

[83] Hislop, E.C. 1988. Electrostatic ground-rig spraying: an overview. *Weed Tech.* 2:94-105.

[84] Squire, D. 1988. County integrates spraying, manual work, P.R. in effort to combat weeds. *Roads & Bridges*. 26(2):42-43.

[85] Heine, M. 1990. Computerized spraying, trucks offer accuracy. *Roads & Bridges*. 28(2):38-40.

[86] Kuennen, T. 1989. Kansas county puts bindweed in bind. *Roads & Bridges* 27(9):80.

[87] Tatman, B. 1989. Roadside maintenance the Ohio way. *Public Works*. 120(3):56-57.

[88] Barrentine, W.L. and C.G. McWhorter. 1988. Johnsongrass (*Sorghum halepense)* control with herbicides in oil diluents. *Weed Science* 36:102-110.

[89] Holt, H.A., L.D. Gualtrey, H.G. Gibson, G.R. Krutz and W.G. Kosinski. 1986. Controlling woody plants with wiping applications. *Proc. Southern Weed Science Society*. 39:364 (Abstract).

[90] Messersmith, C.G. and R.G. Lym. 1985. Roller application of picloram for leafy spurge control in pastures. *Weed Science* 33:258-262.

[91] Waddington, J. and S. Bittman. 1987. Control of brush regrowth in northeastern Saskatchewan by several concentrations of herbicides applied with a roller. *Can. J. Plant Sci.* 67:467-475.

[92] Waddington, J. and S. Bittman. 1987. Effect of number of passes with a roller-applicator using dilute herbicide solutions on control of brush regrowth in northeastern Saskatchewan. *Can. J. Plant Sci.* 67:845-848.

[93] Mayeux, H.S., Jr. and R.A. Crane. 1984. Application of herbicides or rangelands with a carpeted roller: control of goldenweeds (*Isocoma* spp.) and false broomweed (*Ericameria austro-texana*). *Weed Sci.* 32:845-849.

[94] Melichar, M.W. and B.K. Waggoner. 1988. Low-volume basal application of picloram and triclopyr on utility rights-of-way. *Proc. Northeastern Weed Science Soc.* 42:122 (Abstract).

[95] Hall, A.B. and R.J. Hendler. 1985. Control of hardwood brush species with basal applications of triclopyr herbicide. *Proc. North Central Weed Control Conf.* 40:33 (Abstract).

[96] Hall, A.B. and R.J. Hendler. 1986. Performance of low volume basal applications of picloram and triclopyr. *Proc. Northeastern Weed Science Society*. 40:235 (Abstract).

[97] Hendler, R.J., P.L. Burch and F.A. Kidd. 1987. Low volume applications of selective industrial herbicides. *Proc. Southern Weed Science Society* 40:278-287.

[98] Meiichar, M.W., A.B. Hall and R.J. Hendler. 1986b. Low-volume basal application of picloram and triclopyr. *Proc. North Central Weed Control Conf.* 41:114 (Abstract).

[99] Brooks, L.S. and B.S. Jones. 1986. Streamline herbicide release of red pine *(Pinus resinosa)*. *Proc. North Central Weed Control Conf.* 41:107-109.

[100] Kidd, F.A. and M.J. Barton. 1986. Hardwood control from "streamline" basal application of triclopyr and fluroxpyr herbicides. *Proc. North Central Weed Control Conf.* 41:109-113.

[101] Evans, W.F. and T.E. Vrabel. 1990. Basal brush control with herbicide mixtures in Mineral Oil. *Proc. Northeastern Weed Science Society.* 44:122 (Abstract).

[102] Wilson, T.A. 1987. Brush control with dormant season broadcast applications. *Proc. Southern Weed Science Society* 40:272-275.

[103] Lyman, G.T., L.J. Kuhns and A.E. Gover. 1990. Controlling brusl with broadcast dormant stem treatments. *Proc. Northeastern Weed Science Society* 44:128-129. (Abstract).

[104] Corns, W.G. and R.K. Gupta. 1971. Chemical control of cattail, *Typha latifolia*. *Can. J. Plant Sci.* 51:491-497.

[105] Comes, R.D. and A.D. Kelley. 1989. Control of common cattail with postemergence herbicides. *Journal of Aquatic Plant Management*, 27:20-23. (Abstract). Weed Abstracts 1989, Vol. 38:324 (2820).

[106] Sylvester, E.P. 1960. Beware of the wild carrot. *Hoard's Dairyman* 105:330-331.

[107] Chemical used for wild carrot control. *Better Roads*. 1987, 57(7):48,51.

[108] Cramer, G.L. and O.C. Burnside. 1981. Control of common milkweed (*Asclepias syriaca*). *Weed Science* 29:6363-640.

[109] Zollinger, R.K. and J.J. Kells. 1988. Perennial sowthistle (*Sonchus arvensis* L.) co..trol - a three year summary. *Proc. North Central Weed Control Conference* 43:100 (Abstract).

[110] Vidme, T. 1961. Control of *Sonchus arvensis* L. with chemicals. *Weed Res.* 1:275-288.

[111] Nadeau, L.B. and W.H. Vanden Born. 1989. The root system of Canada thistle. *Can. J. Plant Sci.* 69:119-1206.

[112] Friesen, H.A. 1968. Trends in Canadian research to control Canada thistle. *Proc. Northeast Weed Control Conference* 22:27-36.

[113] Olsen, S.J. and N.L. Hartwig. 1988. Problems of Canada thistle in a crown vetch groundcover. *Proc. Northeastern Weed Science Society* 42:75 (Abstract).

[114] Hartwig, N.L. 1990. Thistle control in a crown vetch roadside ground cover. *Proc. Northeast Weed Science Society.* 44:123-125.

[115] Feldman, I., M.K. McCarty and C.J. Scifres. 1968. Ecological and control studies of musk thistle. *Weed Science* 16:1-4.

[116] Welker, J.G. 1984. Cut stubble applications of triclopyr and picloram herbicides following mechanical brush removal on rights-of-way. *Proc. North Central Weed Control Conf.* 39:69-71.

[117] Geyer, W.A., C.E. Long, G.G. Naughton and M.W. Melichar. 1987. Cut-stubble with herbicides on Kansas rights-of-way. *Proc. North Central Weed Control Conf.* 42:85 (Abstract).

[118] Fleischer, S.J., M.J. Gaylor, R. Dickens and D.L. Turner. 1989. Roadside management of annual fleabane (*Erigeron annuus)* and wild carrot (*Daucus carota). Weed Tech.* 3:72-75.

[119] Hodgson, J.M. 1968. The nature, ecology and control of Canada thistle. *U.S. Dept. Agric. Tech. Bull.* 1386.

[120] Doll, J.D. 1988. Roadside weeds: a constant challenge. *Public Works.* 119(3):78-80.

[121] Reece, P.E. and R.G. Wilson. 1983. Effect of Canada thistle (*Cirsium arvense)* and musk thistle (*Carduus nutans)* control on grass herbage. *Weed Science* 31:488-492.

[122] Barrett, J.R. 1990. Control of erosion on roadsides - thoughts, ideas, new materials. In *Beautiful Roadsides - the key to a beautiful America.* Sixth Annual National Roadside Vegetation Management Association Meeting Proc., Nashville, TN. Oct. 3-5, 1989. Pages 16-18.

[123] Johnson, W.D. 1985. Chemically controlling roadside vegetation. *Public Works.* 116(3):64-65.

[124] Ross, R. 1981. Pennsylvania's Roadside Management Program. *Transportation Research Record*. 805:19-20.

[125] King. T.G. and J.O. Sims. 1989. Hydromulching may help control erosion. *Roads & Bridges* 27(2):62-63.

[126] Stafford, R.F. 1982. Fertilization and legume establishment on highway slopes. *Transportation Research Record* 859:19-24.

[127] Duell, R.W. 1987. Roadside vegetation alternatives. *Public Works*. 118(3):77-79.

[128] Committee on Landscape and Environmental Design. 1988. Research problem statements on landscape and environmental design. *Transportation Research Circular* 328.

[129] Johnson, W. D. 1981. Chemical roadside vegetation management program in North Carolina. *Transportation Research Record* 805: 20-21.

[130] Lumis, G.P. and K. Khanna. 1990. *An Evaluation of MTO Specifications for Tree Planting and Maintenance*. Ontario Ministry of Transportation. Research and Development Branch, MAT-90-06.

[131] Potter, C.J. and S. Colderick. 1987. The effect of weeds on tree establishment. *1987 British Crop Protection Conference - Weeds*. Pages 781-785.

[132] Borland, J. 1990. Mulch. *Am. Nurseryman*. August 15:132-143.

[133] Robinson, D.W. 1988. Mulches and herbicides in ornamental plantings. *Hort Science* 23(3):547-552.

[134] Tidwell, B.H. 1989. An award-winning vegetation management program. *Public Works*. 120(3):62-63.

[135] Andresen, J.W. 1981. *Natural Regeneration and Direct Seeding Techniques to Stabilize Ontario's Roadsides*. Ministry of Transportation and Communications. IR73.

[136] Andresen, J.W. and J.E. Gruspier. 1983. *Natural Regeneration Techniques to Stabilize Ontario's Roadsides*. Ministry of Transportation and Communications, Research and Development Branch. RR233.